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SPACE SHUTTLE HYDRAULIC SYSTEMS ASSESSMENT

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DOUGLAS AIRCRAFT COMPANY

MCDONNELL DOUGLAS CORPORATION

Report number MDC J4610

SPACE SHUTTLE

HYDRAULIC SYSTEMS ASSESSMENT

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Prepared by D. F. Greene

D. F. GREENE
PRINCIPAL ENGINEER

Approved by L. F. Kurrasch

L. F. KURRASCH
DIRECTOR–MECHANICAL ENGINEERING

DOUGLAS AIRCRAFT COMPANY

MCDONNELL DOUGLAS CORPORATION

GLOSSARY

APU	Auxiliary Power Unit
ASA	Aerospace Servo Amplifier
BF	Body Flap
CCB	Change Control Board
DAC	Douglas Aircraft Company
ET	External Tank
FAA	Federal Aviation Administration
FCHL	Flight Control Hydraulic Laboratory
FMEA	Failure Modes and Effect Analysis
FTA	Fault Tree Analysis
FO/FS	Fail Operative/Fail Safe
JSC	Johnson Space Center
KSC	Kennedy Space Center
LIE	Left Inboard Elevon
LOE	Left Outboard Elevon
MDC	McDonnell Douglas Corporation
MDTSCO-H	McDonnell Douglas Technical Services Company — Houston
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
OFT	Orbital Flight Test
ORB	Orbiter
OV	Orbital Vehicle
PDU	Power Drive Unit
RI	Rockwell International
RIE	Right Inboard Elevon
ROE	Right Outboard Elevon
R/SB	Rudder/Speed Brake
SAP	Structural Analysis Program
SFC	Single Failure Condition
SFP	Single Failure Point
SRB	Solid Rocket Booster
SSME	Space Shuttle Main Engine
TAEM	Terminal Area Energy Management
TPS	Thermal Protection System
TVC	Thrust Vector Control

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CONTENTS (Continued)

SECTION 1

INTRODUCTION

This report contains the results of an investigation to assess the potential for loss of the Space Shuttle vehicle due to single-point hydraulic system failures.

The assessment was authorized by contracts NA9-14960 and NAS-9-15550, Task Order No. G0908, from the NASA Lyndon B. Johnson Space Center (NASA-JSC) to the McDonnell Douglas Technical Service Company, Houston Astronautics Division supported by the Douglas Aircraft Company at Long Beach, California.

The study was conducted during the 9-month period from October 3, 1977 through June 30, 1978. The purpose of the study was to establish the rationale for retaining the existing hydraulic systems or, alternatively, to identify the rationale for and nature of any appropriate changes. The schedule for the assessment is shown in Figure 1-1.

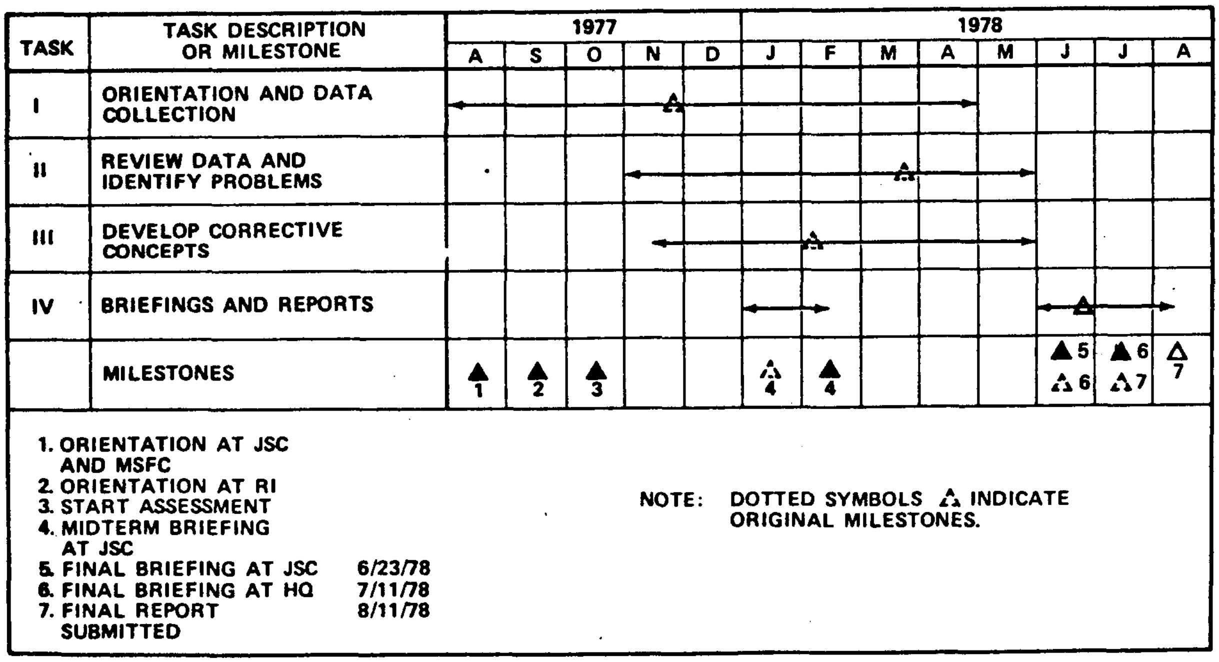

FIGURE 1-1. SCHEDULE SPACE SHUTTLE HYDRAULIC SYSTEMS ASSESSMENT

SECTION 2

SUMMARY

The findings and recommendations included in this report apply to the operational Space Shuttle although some of the recommendations have been incorporated into the Orbital Flight Test (OFT) vehicle. The Booster and Orbiter hydraulic systems were assessed independently except for launch performance effects. The baseline system evaluated was that released for the OV102 OFT vehicle; that system was chosen for study based on the assumption that the OV102 configuration would be carried through into the operational vehicles. Some revisions approved by the NASA Change Control Board (CCB), and for which engineering data were provided, have also been considered.

The assessment of the Solid Rocket Booster (SRB) hydraulic system indicates no major changes are needed for the system architecture. However, numerous items were identified in the power system and thrust vector control (TVC) actuators as single failure points (SFPs) which could result in a Criticality Category 1 condition (loss of life and/or vehicle). The status of these reported SFPs is included in the text of this report. There are also many SFPs in the Orbiter which can result in Criticality Category 1 conditions.

It is the opinion of this assessment team that the reliability requirements of the operational Space Shuttle vehicles, because of their costly payloads and highly trained crews, should be at least equal to those of a military transport. The hydraulic and flight control system architecture as presently designed (for OV102) does not provide this degree of reliability. The elevon system architecture is particularly deficient in this respect. It may be rationalized that with extensive quality assurance activities, a limited number of test flights may be an acceptable risk. However, for the 10-year biweekly operational flight program, the risk appears to be excessive.

SECTION 3

INVESTIGATION

3.1 ASSESSMENT TEAM MEMBERS

J. A. Chamberlin McDonnell Douglas Technical Service Co. Houston, Texas	Technical Manager
D. F. Greene, Senior Engineer Mechanical Engineering Department Douglas Aircraft Co. Long Beach, California	Principal Engineer
D. E. Evans, Senior Engineer Mechanical Engineering Department Douglas Aircraft Co. Long Beach, California	Hydraulic Systems
C. H. Goldthorpe, Senior Engineer Mechanical Engineering Department Douglas Aircraft Co. Long Beach, California	Servocontrols
D. M. Beck, Senior Engineer Reliability and Safety Engineering Department Douglas Aircraft Co. Long Beach, California	Safety and Reliability
J. Little, Consulting Engineer Senior Hydraulic Engineer Douglas Aircraft Co. Long Beach, California	Architectural Assessment

3.2 ORIENTATION AND DATA COLLECTION

Presentations at NASA-JSC and NASA-MSFC were provided the assessment team prior to commencement of the study in order to orient the team with the Space Shuttle design requirements, construction, and performance. The known areas of hydraulic system reliability concern were described. The team then proceeded to the Rockwell International facility at Downey, California where the Space Shuttle mockup and various test facilities were examined. Numerous technical and historical documents were provided the team for study and to illustrate the baseline for Orbital Flight Test (OFT) vehicle

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OV102. As a result of these orientation activities, the assessment team prepared a preliminary list of drawings and data needed to accomplish the requested hydraulic system assessment. This list was periodically expanded as additional necessary information was identified (reference Appendix C).

The NASA Task Monitor, R. D. White, provided the interface with the Space Shuttle technical managers, contractors, and vendors to define the OV102 baseline systems and the planned or contemplated modifications of the current baseline. In addition, he obtained and provided the assessment team with appropriate system design and installation drawings, equipment specifications, detailed drawings of the components, system test configurations, and test results.

3.3 SYSTEMS REVIEW

Information defining the Solid Rocket Booster (SRB) was received in sufficient quantity to permit commencement of the assessment the first week in October 1977. As additional data and documents for the SRB and Orbiter were supplied, they were catalogued until sufficient information for each subsystem or component was on hand to permit assessment. (Lists of documents and drawings supplied by NASA are included in Appendix C.)

Drawings and documents defining the hydraulic systems on the SRB and Orbiter vehicle were examined by team members to accomplish the following:

1. Assess the potential for loss of the operational Space Shuttle vehicle due to failures in the hydraulic/actuation systems. Primary consideration was given to single-point hydraulic-system failures (e.g., seals and hydraulic system interconnections).

2. Identify viable system/subsystem alternatives required to correct any system deficiencies disclosed, taking into consideration reliability, system impact, and program posture. The gross cost, weight, schedule implications, and design concepts were given for the alternative systems identified. The compatibility of any proposed alternative systems with the current vehicle systems (structures, avionics, hydraulics) was studied, considering the design and test maturity of the vehicles at this point in the program.

3. Consideration was given to the impact on the total vehicle, the test program schedule, the Orbital Flight Test (OFT), and the Shuttle vehicle production schedule. The possibility of phasing in a proposed upgraded configuration, at an effectivity which will avoid significant impact on the planned flight schedule, was also considered.

The assessment effort was broken into three major elements: (1) power and utility systems, (2) servo control systems, and (3) system architecture. To facilitate the identification of single failure points (SFPs) and single failure conditions (SFCs), a fault tree was generated to provide a pictorial representation of the sequence of events leading from an SFP or SFC to the vehicle loss. These SFPs and SFCs were determined by examining the reliability and safety documentation and by examining schematic diagrams, assemblies, and detail drawings of the hydraulic systems. Checklists were also developed (see Appendix D) to aid in identifying design deficiencies.

3.3.1 Space Shuttle Fault Tree Analysis

3.3.1.1 Purpose and Scope — The Fault Tree Analysis (FTA), illustrated in Figure 3-1, was prepared to assure that all SFPs leading to Criticality Category 1 hazards were identified and analyzed. The FTA was chosen as an analytical tool for use in performing the assessment because it is an orderly, logical analysis method and because it provides overall visibility — that is, a pictorial representation — of the hazards and their relationships.

The FTA includes all the SRB and Orbiter hydraulic system effectors — i.e., elevons, rudder/speed brake, body flap, External Tank (ET) umbilical retract, landing gear, brakes, SSME fuel and thrust vector controls, and SRB TVC, as well as their associated power distribution systems. It is a qualitative analysis; that is, it does not give values for failure rates and probability numbers are not calculated. A qualitative FTA was selected rather than a quantitative one because of the difficulty in obtaining valid failure rate data for equipment that is essentially tailor-made for Space Shuttle application and for which no failure history exists. However, the number of problem items (e.g., SFPs) is given in order to indicate the magnitude of the overall hazard level for the vehicle.

The FTA is based upon data produced by previously performed failure modes and effects analyses (FMEAs), safety analyses, hazard analyses, and other reviews and studies of the hydraulic system. The sources for these data are included in the list of documents, Appendix C, of this report. In particular, the FTA is based upon the MDC assessment of the hydraulic system and its equipment.

The FTA is separated into four portions corresponding to the various phases of a flight, namely the ascent (including prelaunch), entry/TAEM, approach and landing, and rollout. Separation of the FTA into these phases was based on the effectors used during each phase and the associated Criticality Category 1* hazard criteria. For example, the effectors used during the phases are: during ascent, the SRB TVC, SSME TVC, and elevons; during entry/TAEM, the aerosurfaces; during approach and landing, the aerosurfaces plus the landing gear; and during rollout, the braking and steering systems. The abort and on-orbit phases were not included because of the large number of failure conditions that could be postulated for abort situations, and because the hydraulic systems are nonoperational and at low pressure while in orbit.

*Loss of life and/or vehicle.

ASCENT

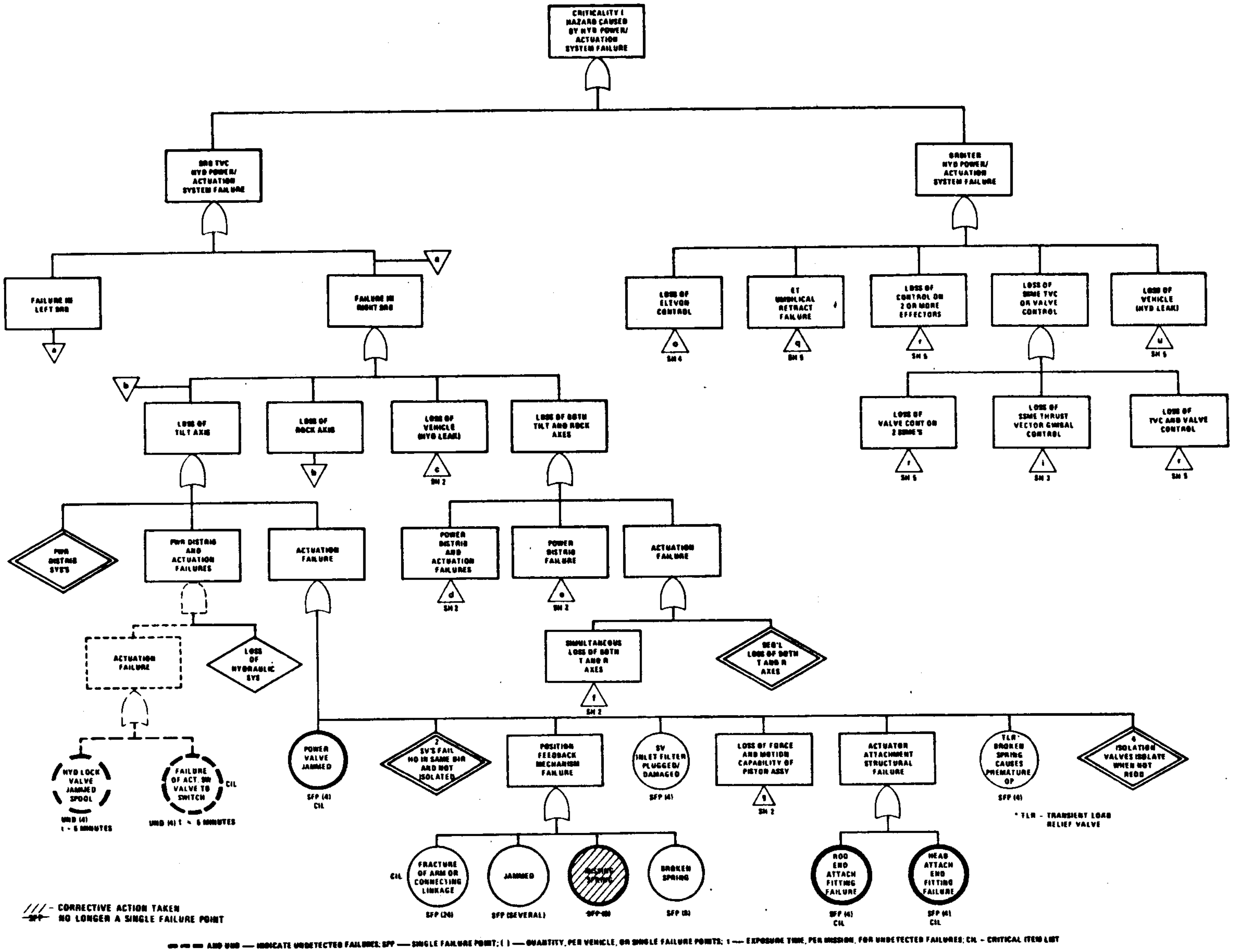
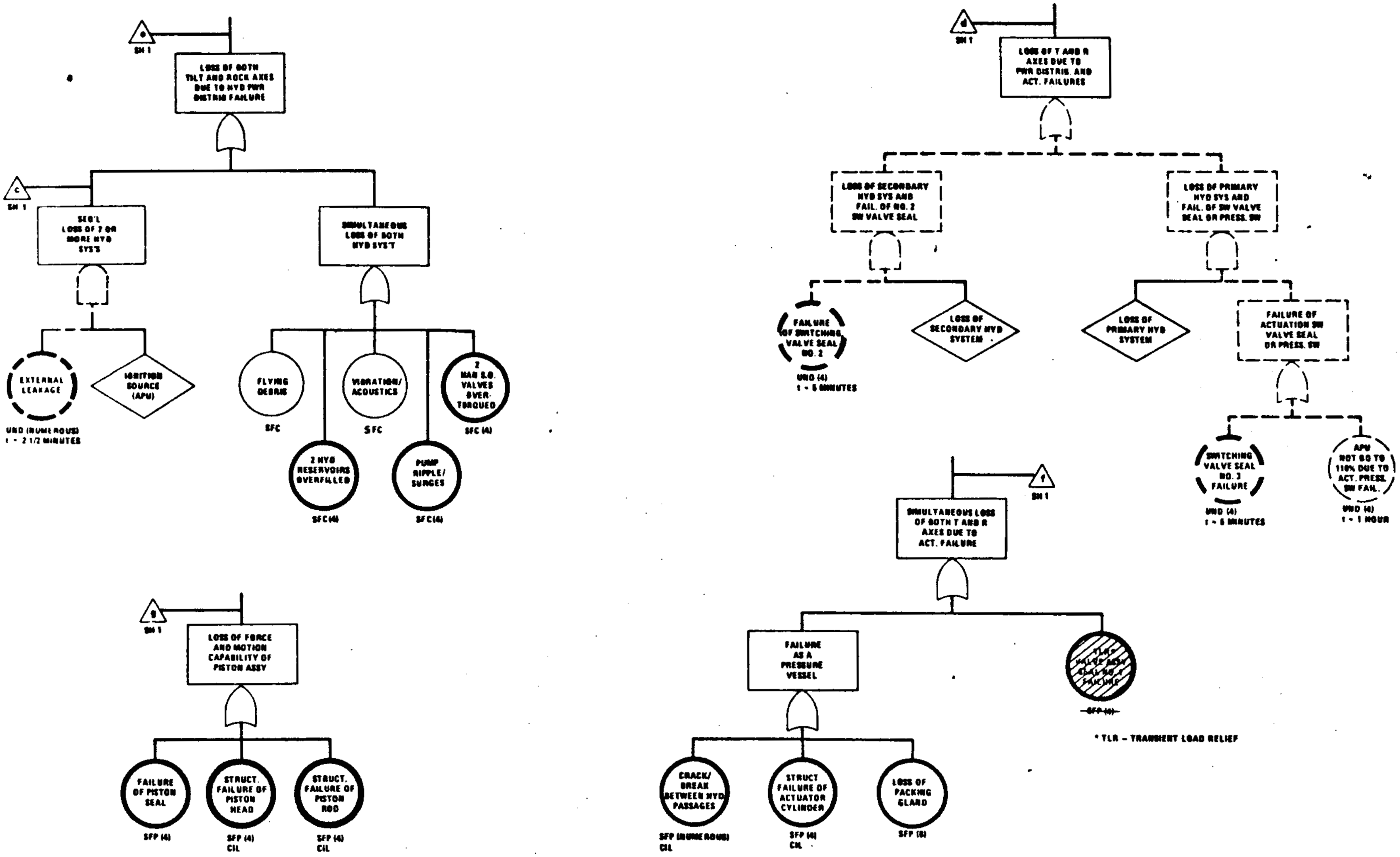


FIGURE 3-1. SPACE SHUTTLE FAULT TREE

ASCENT (CONTINUED)

SHEET 2 OF 8



SFC – SINGLE FAILURE CONDITION; ⬚ ⬚ ⬚ AND UND ——— INDICATE UNDETECTED FAILURES; t ——— EXPOSURE TIME PER MISSION FOR UNDETECTED FAILURES; CIL CRITICAL ITEM LIST

FIGURE 3-1. SPACE SHUTTLE FAULT TREE (CONTINUED)

ASCENT (CONTINUED)

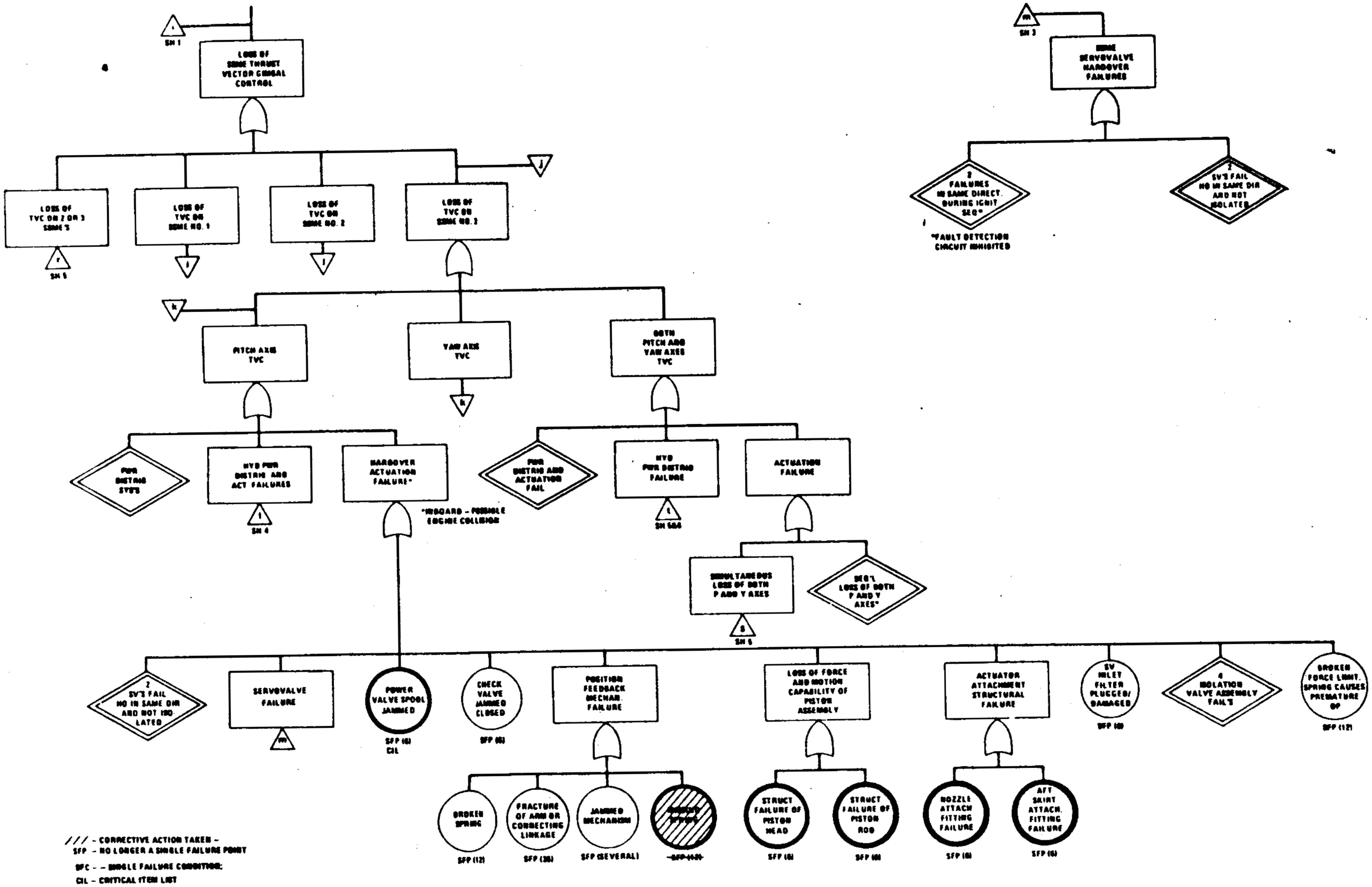


FIGURE 3-1. SPACE SHUTTLE FAULT TREE (CONTINUED)

ASCENT (CONTINUED)

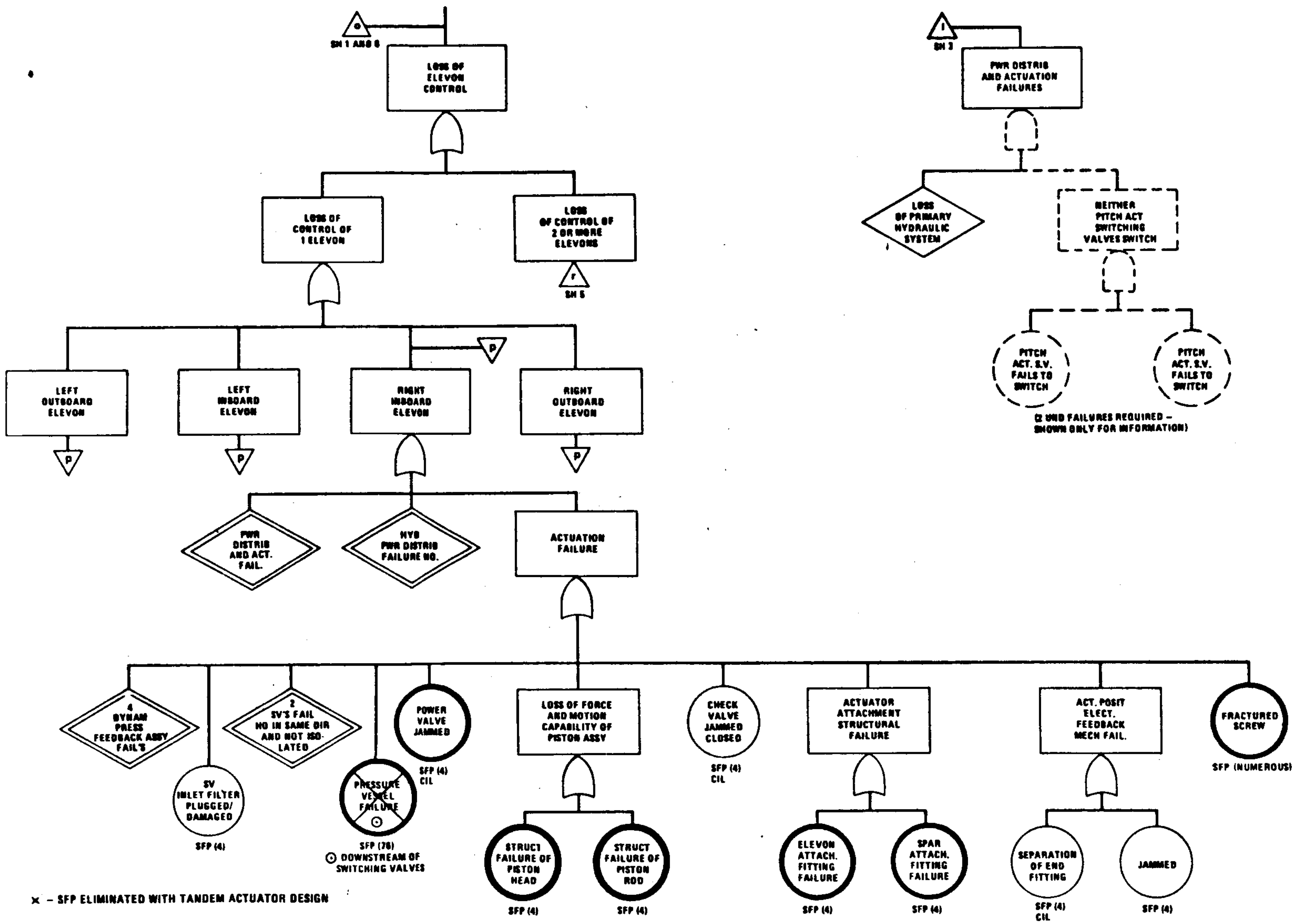


FIGURE 3-1. SPACE SHUTTLE FAULT TREE (CONTINUED)

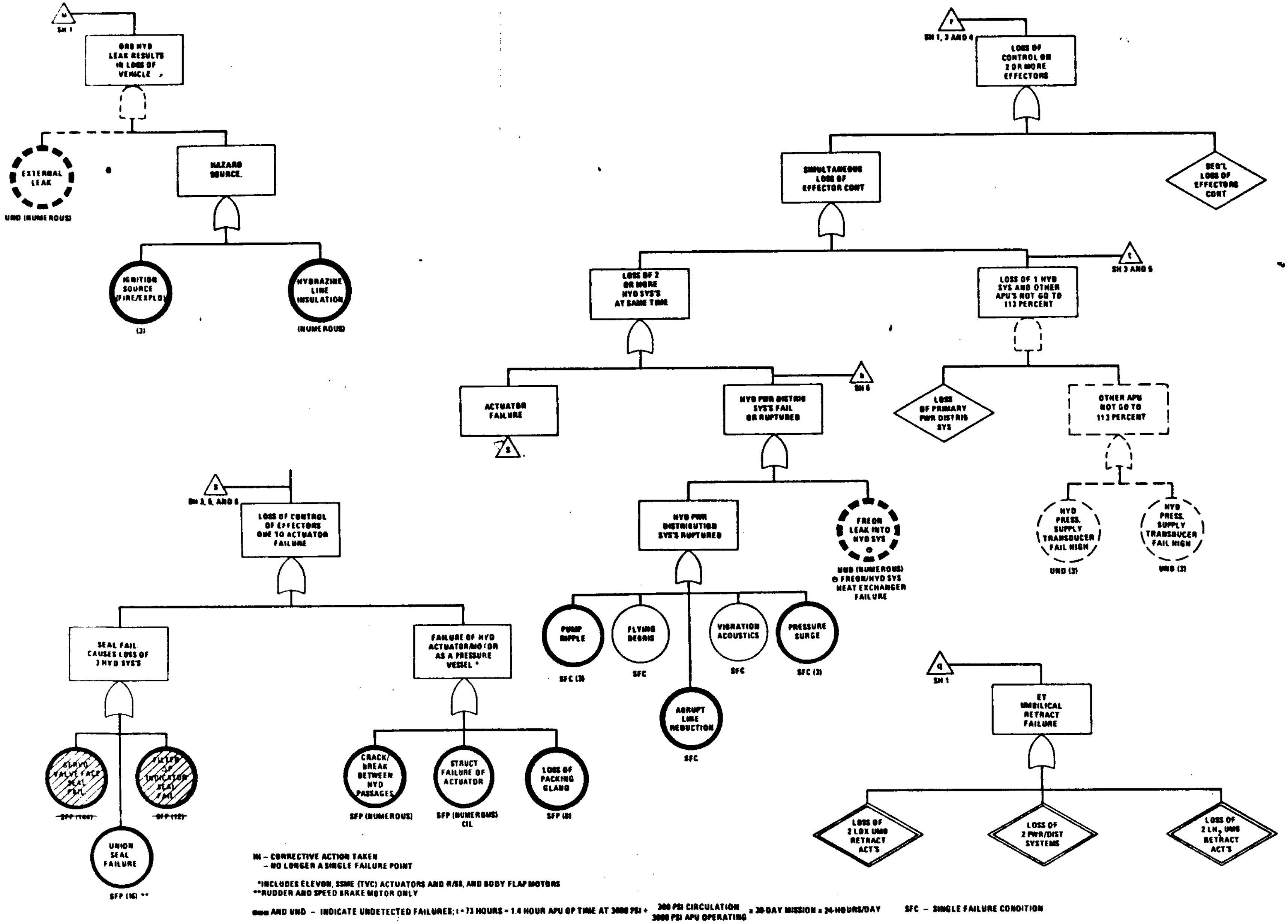
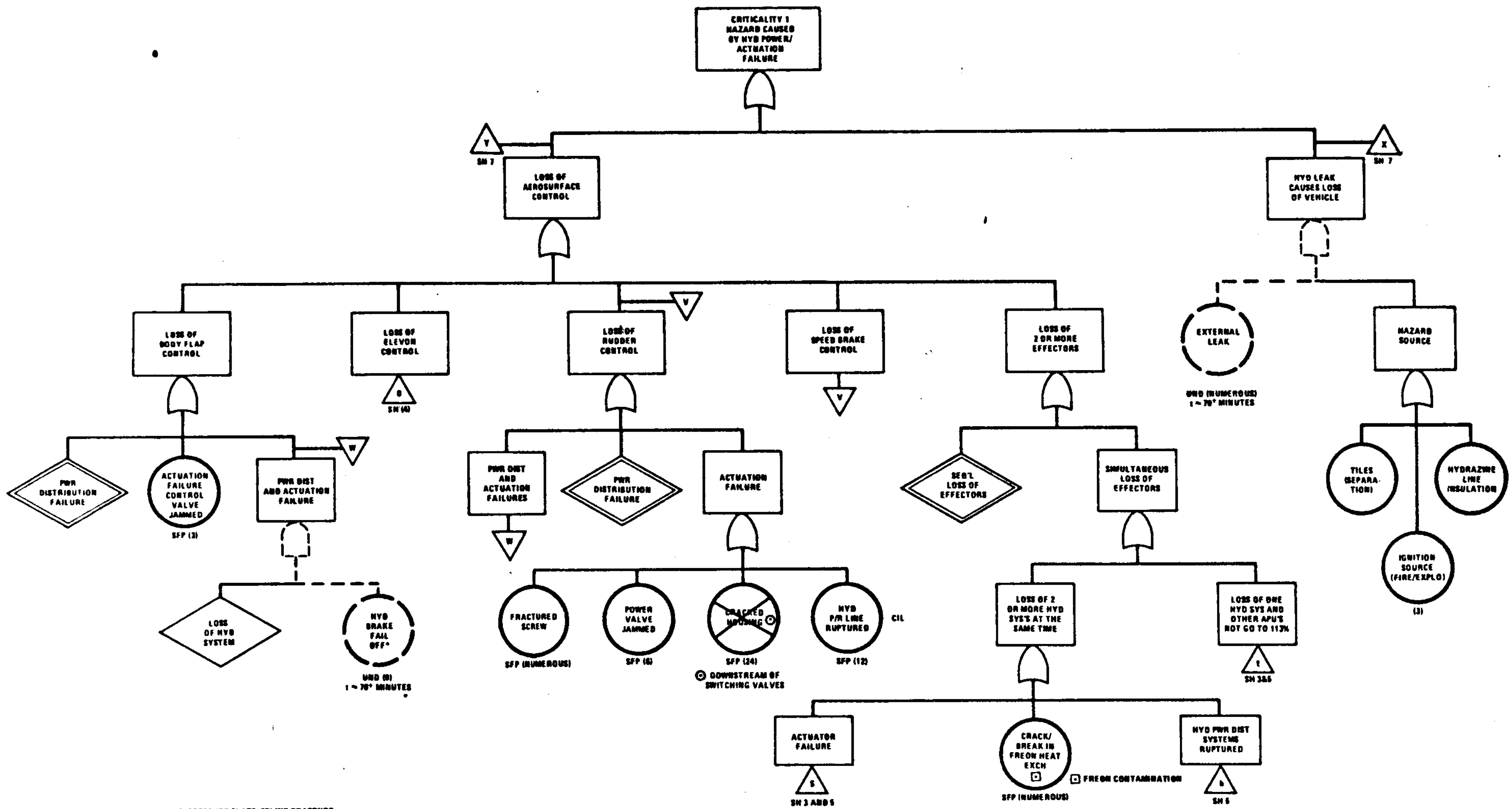


FIGURE 3-1. SPACE SHUTTLE FAULT TREE (CONTINUED)

ENTRY AND TAEM

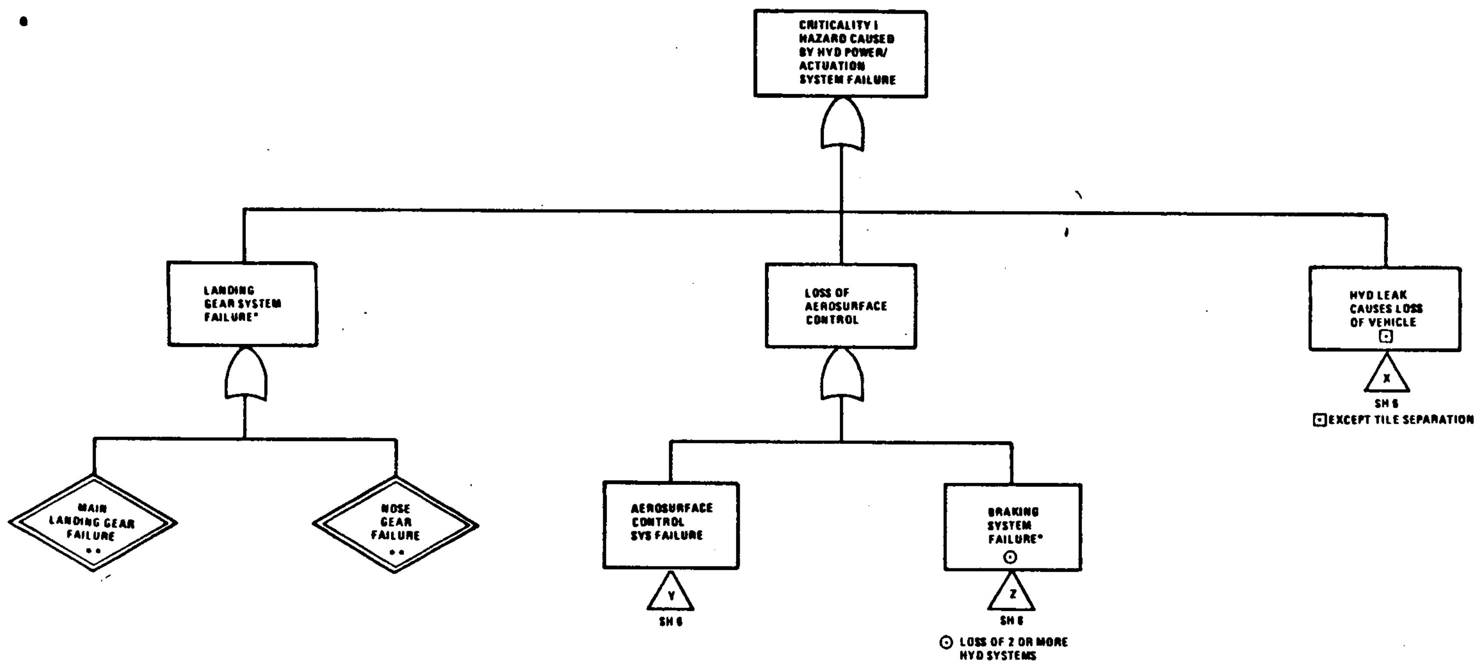


*ACTUATING SPRING, PRESSURE PLATE, SPLINE FRACTURE
**INCLUDES ALL AEROSURFACE ACTUATORS, EXCEPT BODY FLAP.
/// - CORRECTIVE ACTION TAKEN.
- NO LONGER A SINGLE FAILURE POINT.
AND UND - INDICATE UNDETECTED FAILURES
t - EXPOSURE TIME, PER MISSION, FOR UNDETECTED FAILURES
X - SFP ELIMINATED WITH TANDEM ACTUATOR DESIGN
CIL - CRITICAL ITEM LIST

FIGURE 3-1. SPACE SHUTTLE FAULT TREE (CONTINUED)

APPROACH AND LANDING

SHEET 7 OF 8



*SHORT TIME DURATION (LESS THAN ONE MINUTE). SYSTEM ISOLATED PRIOR TO EXTENSION OF LANDING GEAR.
**ORDNANCE UNLATCH PROVISIONS AND FREE FALL CAPABILITY

FIGURE 3-1. SPACE SHUTTLE FAULT TREE (CONTINUED)

ROLLOUT

SHEET 8 OF 8

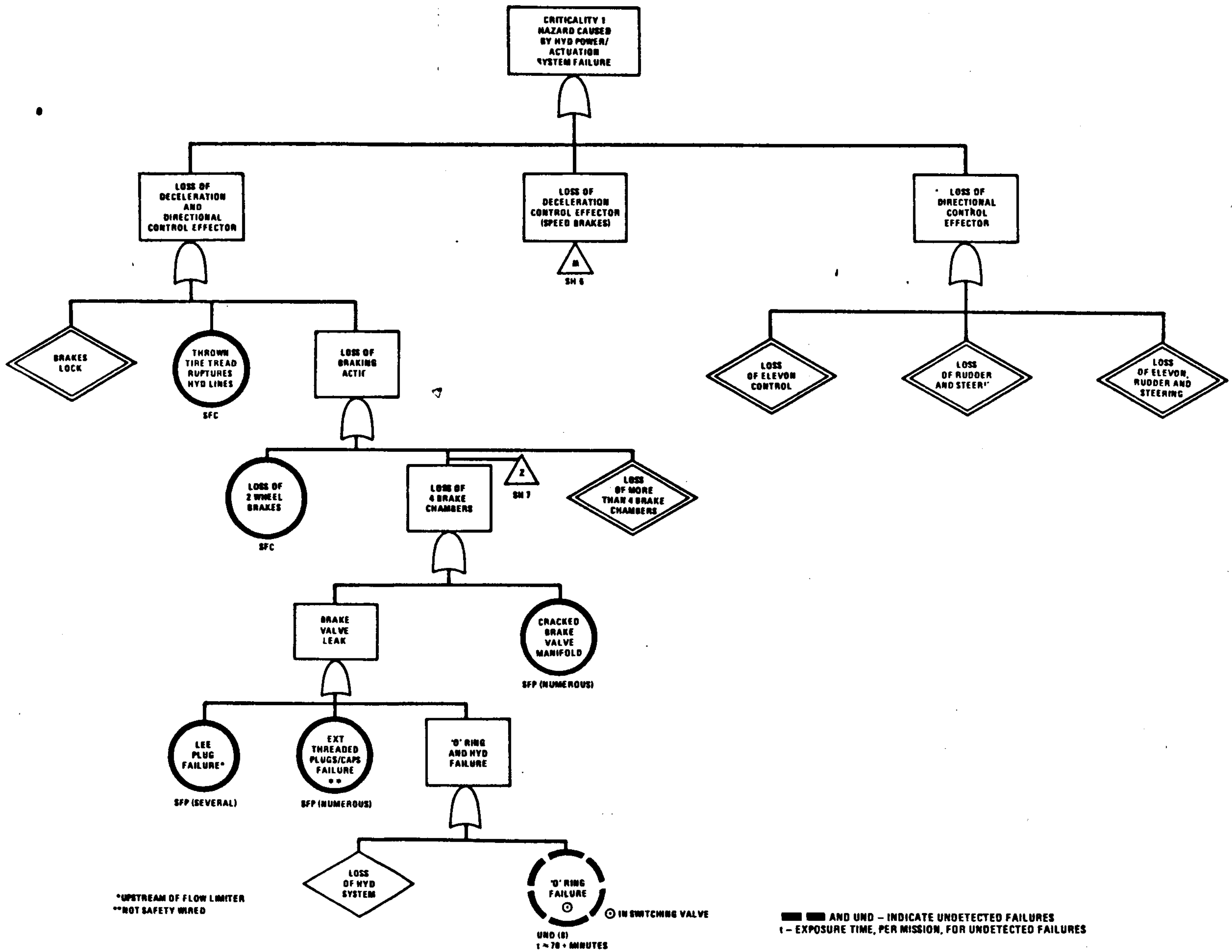


FIGURE 3-1. SPACE SHUTTLE FAULT TREE (CONTINUED)

3.3.1.2 Criticality Category 1 Hazard Criteria — The Fault Tree Analysis and the MDC assessment are based on failures of the hydraulic subsystem that could result in loss of life and/or the vehicle. Therefore, the guidelines used to determine such failures were the Criticality Category 1 hazard criteria. These criteria are, of course, different from abort criteria. The Criticality Category 1 hazard criteria (hereafter referred to as the hazard criteria) are given below for the various mission phases.

For the ascent phase, the analysis includes both the SRB and Orbiter. For the SRB, the hazard criterion is loss of TVC on one or both axes. The hazard criteria during ascent for the Orbiter are:

- Loss of control of one or more elevon surfaces
- Loss of one SSME TVC (i.e., possible engine collision)
- Loss of fuel control on two SSMEs
- Loss of two or more ET umbilical retractors on either ET umbilical
- Loss of two or more effectors
- Loss of vehicle due to hydraulic leaks
- Loss of control due to failures in passive effectors that have hydraulic pressure applied to them (i.e., rudder, speed brake, and body flap).

During the entry/TAEM phase, the hazard criteria are:

- Loss of control of one or more elevon surfaces
- Loss of speed brake control
- Loss of rudder control
- Loss of body flap control
- Loss of two or more effectors.

The SSME TVC actuators, SSME fuel controls, and umbilical retraction systems are isolated by shutoff valves after the ascent phase (ET separation). The landing gear, braking, and steering systems are isolated by shutoff valves until the approach and landing phase (landing gear commanded down).

In the approach and landing phase, the hazard criteria consist of:

- Same as entry/TAEM, plus failure of landing gear — main and nose — to extend and lock.

Note that the worst case essentially has been assumed, since in some situations a safe landing may be made even if one of the effectors is lost. For example, it may be possible to land the Orbiter without body flap control if the cg is within certain limits and the environment is benign.

During rollout, a catastrophic hazard could occur due to:

- Loss of braking control (i.e., loss of one or more wheel brake chambers)
- Loss of speed brake control
- Loss of elevon control (two or more surfaces)
- Loss of rudder and nose wheel steering
- Loss of two or more effectors.

The rollout analysis was based on failures which occur during higher rollout velocities,* that is for velocities at which the rudder, speed brake, or elevons are effective. The higher rollout velocities were used in the analysis for two reasons. First, at the lower velocities the aerosurfaces become ineffective and their loss would be either inconsequential or possibly result in some damage to the vehicle, but it would not be a Criticality Category 1 hazard. Second, a main consideration in causing loss of control during rollout is the marginal nature of braking at the higher velocities. For example, if rudder control were lost at touchdown, subsequent excessive braking might occur causing blown tires, loss of directional control, or running off the side of the runway at high speed.

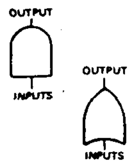
3.3.1.3 Fault Tree Analysis Development — The FTA is a top-down approach to failure analysis, i.e., the fault tree starts with an undesired event — a Criticality Category 1 hazard in the case of the Hydraulic System Hazard Assessment — and then identifies the various ways it can happen. This contrasts with the approach used in an FMEA. An FMEA can be thought of as a bottom-up approach where modes of system/component failures are identified and the effects on the vehicle are evaluated.

The fault tree itself is a graphic presentation showing the system relationships among fault events. Three types of symbols are used in a fault tree — logic, event, and transfer, as shown in Figure 3-2. The logic symbols (gates) are used to interconnect the events that contribute to the specified main (TOP) event. The logic gates that are used most frequently to develop fault trees are the basic AND and OR Boolean expressions. The AND gate provides an output event only if all input events exist concurrently. The OR gate provides an output if one or more of the input events are present.

The event symbols are the rectangle, circle, and diamond. The rectangle represents a fault event resulting from a combination of more basic faults acting through logic gates. The diamonds and circles are basic fault events, as described in Figure 3-2, and represent the lowest level of development of the fault tree.

The triangle indicates a transfer from one part of the fault tree to another. Triangles are used in two ways. One is to transfer the development of the fault tree to another page.

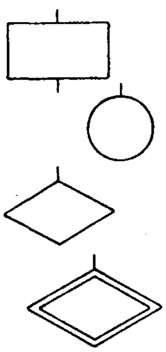
*Loss of brakes was also considered to be catastrophic at slower rollout velocities.



LOGIC OPERATIONS (GATES)

THE "AND" GATE DESCRIBES THE LOGICAL OPERATION WHEREBY THE COEXISTENCE OF ALL INPUT EVENTS IS REQUIRED TO PRODUCE THE OUTPUT EVENT.

THE "OR" GATE DEFINES THE SITUATION WHEREBY THE OUTPUT EVENT WILL EXIST IF ONE OR MORE OF THE INPUT EVENTS EXISTS.



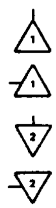
EVENT REPRESENTATIONS

THE RECTANGLE IDENTIFIES AN EVENT THAT RESULTS FROM THE COMBINATION OF FAULT EVENTS THROUGH THE INPUT LOGIC GATE.

THE CIRCLE DESCRIBES A BASIC FAULT EVENT THAT REQUIRES NO FURTHER DEVELOPMENT, E.G. SINGLE FAILURE POINTS. (SEE FIGURE 3-3 FOR DEFINITION OF SINGLE FAILURE POINT SYMBOLS USED IN THE ASSESSMENT.)

THE DIAMOND IDENTIFIES A BASIC FAULT EVENT WHICH IS NOT DEVELOPED FURTHER BECAUSE THE EVENT DOES NOT PRESENT A HAZARD BY ITSELF BUT ONLY WHEN COMBINED WITH AN UNDETECTED FAILURE.

THE DOUBLE DIAMOND IS USED TO DESCRIBE A FAULT EVENT THAT IS CONSIDERED BASIC IN A GIVEN FAULT TREE. THE POSSIBLE CAUSES OF THE EVENT ARE NOT DEVELOPED, BECAUSE MULTIPLE, INDEPENDENT, DETECTABLE FAILURES MUST OCCUR AND THUS THE LIKELIHOOD OF FAILURE IS INSIGNIFICANT COMPARED TO THE SINGLE FAILURE POINTS.



TRANSFER SYMBOLS

THE TRIANGLES ARE USED AS TRANSFER SYMBOLS. A LINE FROM THE TOP OF THE TRIANGLE INDICATES A "TRANSFER IN" AND A LINE FROM THE SIDE DENOTES A "TRANSFER OUT."

THE UPRIGHT TRIANGLE (△) IS USED WHERE THE SEQUENCE OF EVENTS BEING TRANSFERRED TO ANOTHER PART OF THE FAULT TREE IS TO HAVE ALL IDENTICAL EVENTS IN BOTH LOCATIONS.

THE INVERTED TRIANGLE (▽) IS USED WHERE THE SEQUENCE OF EVENTS BEING TRANSFERRED TO ANOTHER PART OF THE FAULT TREE IS TO HAVE ONE OR MORE DIFFERENT EVENTS IN THE SECOND LOCATION BUT IS TO BE IDENTICAL IN FUNCTION.

FIGURE 3-2. FAULT TREE ANALYSIS SYMBOLS

This is necessary because of the limited space available on a page to complete the entire fault tree. Second, triangles indicate that an identical development applies in another portion of the fault tree but is not repeated in order to save space and reduce the complexity of the fault tree. Upright triangles are used for the first case and inverted triangles are used in the second case, as described in Figure 3-2. In order to facilitate locating transfers to another sheet (page) of the fault tree, the number of the sheet where the development is shown is given under the upright triangle after the letters SH.

In the Space Shuttle FTA, circles are depicted in five ways, as shown in Figure 3-3. First, the circles outlined with thin lines indicate SFPs that exist in the hydraulic system that have been analyzed by both NASA and MDC and determined to present an acceptable risk. Second, the dark circles highlight SFPs determined by MDC to be significant problem items. (A significant problem item is one in which an undue risk exists of a Criticality Category 1 hazard occurring with the present design.) MDC has recommended corrective action to reduce the risk for each of the significant problem items. Third, dashed circles with UND under the circle indicate that the SFP failure is not detected in flight. This constitutes an undetected failure case (1U), as explained in Paragraph 3.3.1.4. Fourth, the cross-hatched dark circles indicate that corrective action

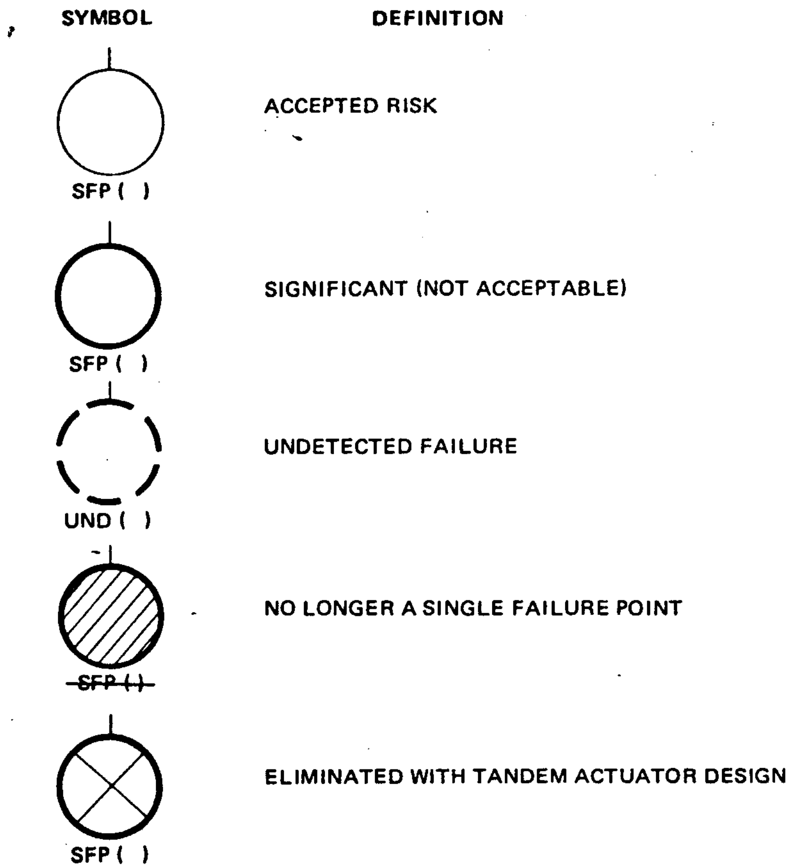


FIGURE 3-3. SINGLE FAILURE POINT SYMBOLS

taken will eliminate the significant problem as an SFP. In addition, the SFP and quantity in parentheses under the cross-hatched circle have lines through them to indicate that the SFP no longer exists. Fifth, an X through a circle indicates that the SFP for the present design would be eliminated by use of the actuator designs proposed by MDC.

The quantity of single failure points per vehicle for that SFP is shown in parentheses below each point. For undetected failures (dashed circle), an estimated exposure time during which the failure could occur and a subsequent failure could result in a Criticality Category 1 hazard is shown below the dashed circle (see examples in Figure 3-1).

An important fact concerning single failure points on an FTA is that although the SFP appears near or at the bottom of the fault tree, it can directly cause a main (TOP) event to occur. This is the case any time a path can be followed from the failure point through OR gates to the TOP event. By this means, SFPs can be easily recognized on a fault tree.

3.3.1.4 Assessment Criticality Category 1 Failure Summary — Figure 3-4 summarizes the Criticality Category 1 items in the SRB and Orbiter hydraulic actuation systems. The majority of the causes of a catastrophic hazard (Criticality Category 1

CATEGORY OF FAILURE (CRIT)	POWER DISTRIBUTION		CONTROL ACTUATION		SUBTOTAL		TOTAL
	SRB	ORB	SRB	ORB	SRB	ORB	VEHICLE
SINGLE FAILURE POINT (1)	LEAKS	LEAKS	32	203	32	203	235
UNDETECTED FAILURE (1U)	LEAKS	—	16	13	16	13	29
SINGLE FAILURE CONDITION * (1)	16	9	—	—	16	9	25
TOTALS	16	9	48	216	64	225	289**

* CONDITION THAT IF IT OCCURS CAN RESULT IN LOSS OF TWO OR MORE HYDRAULIC SYSTEMS SIMULTANEOUSLY (E. G., APU FLYING DEBRIS)

** NOT INCLUDING LEAKS

FIGURE 3-4. CRITICALITY CATEGORY 1 SUMMARY – OPEN SIGNIFICANT ITEMS

condition) are single failure points. Of the 235 SFPs in the vehicle, 203 are in the Orbiter and 32 in the SRB. For the SRB, all the failures are of concern, of course, during the ascent phase. The combination of possible SRB and Orbiter SFPs (together with the undetected failures and single failure conditions) during ascent makes that phase the phase during which the largest number of Criticality Category 1 hazard conditions exist. Ascent is also the phase during which the most severe environmental conditions exist (except possibly during the entry phase). However, the ascent phase is of relatively short duration — about 2 minutes for the SRB and about 13 for the Orbiter.

The phases presenting the greatest hazard to hydraulic systems may be the later ones because significantly greater time exists for occurrence of Criticality Category 1 failures. For example, the exposure time for a catastrophic failure during ascent for the SRB — about 2 minutes — compares with an exposure time for failure of an aerosurface actuator or an external leak that could be as long as 43,200 minutes for a 30-day mission. Note: The great majority of the 43,200 minutes would be on-orbit time during which the hydraulic pressure in the hydraulic systems is considerably reduced and the actuators are not operating. Nevertheless, the possibility that a failure will occur during the long exposure time on orbit is a definite factor in considering the overall chance of failure occurring during the mission.

In regard to long failure exposure times, the effects of undetected failures were studied in the assessment. An undetected failure is defined as "a passive failure in flight that is not detected and annunciated and its effects are unobservable." Thus it is a failure that is unknown to the flight or ground crew. Accordingly, the failure can exist undetected for a long period of time.

The undetected failure does not by itself create a hazardous situation; however, it becomes critical when, combined with a subsequent failure, it precipitates a catastrophic accident. This is particularly significant in the cases where the subsequent failure would not otherwise present a hazard. An example is loss of a hydraulic system. Loss of one hydraulic system could be the cause for an abort, but the vehicle and crew could be safely recovered; thus the hydraulic system loss would not be a catastrophic, Criticality Category 1 hazard. However, if a body flap hydraulic brake had previously failed to the off condition (an undetected failure), then the loss of one hydraulic system could be catastrophic due to loss of body flap control.

The significant point is that after an undetected failure, the flight will continue without the crew knowing they are one failure away from the drastic consequences of a single failure — *a single failure that has a relatively high probability of occurring and that now will be catastrophic.* This is in contrast to the situation where the first failure is detected and the flight crew can prepare for a subsequent failure by aborting, returning to earth early, deactivating certain equipment, etc.

Inherent in the meaning of failure detection is that the occurrence of the failure is made known to the flight or ground crew within a reasonably short time. A failure that is detected only by telemetry and is recorded on tape along with other data, and is not looked at for a long time afterward, is not classified as a "detected" failure since it was not known soon after its occurrence.

The undetected failures have been categorized as Criticality Category 1U in the assessment. The 1U category indicates that a failure can occur without being known and, during the time subsequent to this failure — which can be a long time — the occurrence of one more failure can result in a Criticality Category 1 hazard.

A Criticality Category 1U failure and a Criticality Category 1R failure differ in two ways. First, Criticality Category 1R is used to indicate that an undetected failure could occur in a redundant component of a critical system., A Criticality 1R failure results in loss of part of a redundant system without the loss being known. However, there may be no single additional failure subsequent to and in combination with the 1R failure that would result in a catastrophic accident. Second, a Criticality Category 1R failure *must* occur in a redundant component whereas a Criticality 1U failure *may* occur in a redundant or a nonredundant component.

A feature that is common to both the Criticality 1R and 1U failures is that it is especially important to assure that they are checked for prior to each flight. The 1R- and 1U-type failures should be checked for during the prelaunch checks and as near to liftoff as possible in order to reduce the exposure time for such failures and thus reduce their likelihood of occurrence.

The single failure conditions (SFCs) in the assessment refer to conditions such as pump ripples and surges or vibration and acoustics which could cause the hydraulic system to fail. An SFC is not a failure of a hydraulic system component; however, each SFC represents a single failure cause that could result in loss of two or more hydraulic systems, a Criticality Category 1 hazard, and thus is included in the assessment.

3.3.2 Power and Utility Systems

3.3.2.1 Solid Rocket Booster — There are three situations in the SRB hydraulic power systems where a single condition or generic fault may result in a Criticality Category 1 failure. These are (1) reservoir overfilling, (2) pump pressure line failure, and (3) mounting of a manual shutoff valve.

3.3.2.1.1 Reservoir Overfilling — Each solid rocket booster has two hydraulic power systems. The assessment team was informed that the hydraulic reservoir in each system is to be filled 70 percent full prior to operation; however, no documentation for this requirement was provided. There is an automatic launch hold if the reservoir is less than 50 percent full, but there is no similar upper limit. If a reservoir were filled above 86 percent at ambient temperature, it probably would burst in flight. This would occur because the system temperature increases about 180°F and this would cause sufficient expansion of the oil to bottom the reservoir piston. When this occurred, the reservoir oil pressure would rise and the low pressure relief valve would open. The exhaust line on this relief valve is capped in flight at the service panel. For this reason, the reservoir pressure cannot be relieved and the reservoir would burst.

If the above situation is combined with a previously undetected failure in the second system, the result would be a Category 1U failure. It could well be that the person assigned to fill the reservoirs would overfill both of them. This would be a generic problem in which a single personal error would result in a dual failure, and loss of both hydraulic systems. This would be a Criticality Category 1 condition.

The following actions are recommended to correct this condition:

1. Provide an overboard vent which is open in flight for the low-pressure relief valve. This is a preferred solution.

2. As an alternative, the following may be done:

- Limit maximum oil fill volume to 80 percent of reservoir capacity.
- Check reservoir volume at countdown.
- Provide an automatic launch hold for both minimum and maximum oil volume.

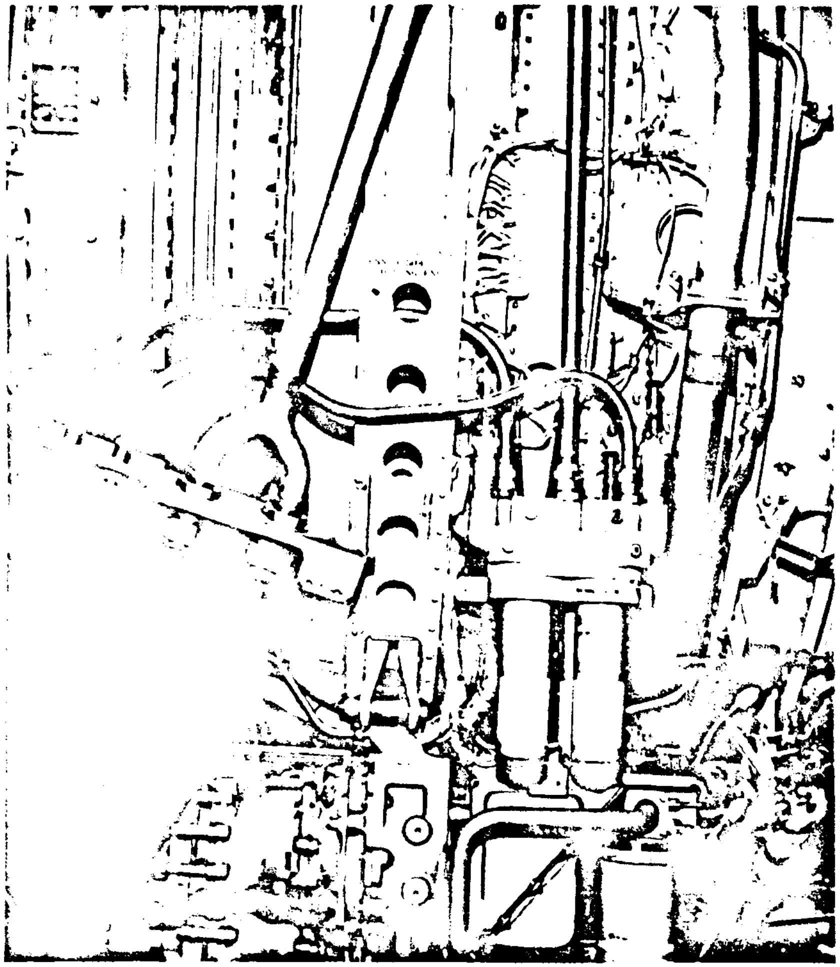
3.3.2.1.2 Pump Pressure Line Failure — The pump pressure line is a short length of hose followed by a hard line to the check valve and filter. The length of hose and hard line is within a few inches of the same length as the original Douglas DC-10 aircraft pump hose lines. The DC-10 installation developed a serious problem because of pump ripple with 1250-psi peak-to-peak pressure variations. This resulted in several line failures at a life of approximately 40 hours. After considerable analysis, and test of several configurations, a satisfactory solution was found that reduced pump ripple to 125 psi peak-to-peak yet did not reduce operating life. It consisted of a pump ripple attenuator, a small hollow spheroid about 5 inches in diameter, and a longer hose. The configurations, both before and after, are shown in Figure 3-5.

The configurations of the SRB and DC-10 pump line routings are sufficiently alike to cause concern that the SRB would encounter this kind of problem. The tests conducted on the SRB system did not incorporate a pressure transducer next to the pump. The only pressure measurement taken was inside the fluid manifold assembly using a normal response transducer. Pressure measurements were recorded only five times per second. It is most unlikely that this test would reveal the existence of a pump ripple problem.

It is recommended that pump ripple and its effect on the operating life of the line be determined. The Douglas experience with this type of problem indicates that the test article must be the same as that used in production assembly. In addition, only a high-response (10 kHz) instrument such as a Kistler pressure transducer will provide accurate data. It is furthermore necessary to display the Kistler output on an oscilloscope or continuous high-speed recorder. Pressure measurements should be made at both ends of the pump pressure line. In our experience, these things are mandatory to evaluate the problem. With an average life as low as 40 hours, the probability of a dual generic failure becomes unacceptably high. If the existing pressure line configuration has insufficient life, some combination of a longer hose and a pressure attenuator chamber may be required.

3.3.2.1.3 Manual Shutoff Valve — Two manual bleed valves are provided for each hydraulic power system on the Solid Rocket Booster. These valves are mounted by clamping the valve body in a circular hole in the service panel with a jam nut. This is shown in Figure 3-6. The valve is opened and closed by applying a wrench torque to the projecting hexagonal stem. If excessive torque is applied when opening or closing the

BEFORE



AFTER

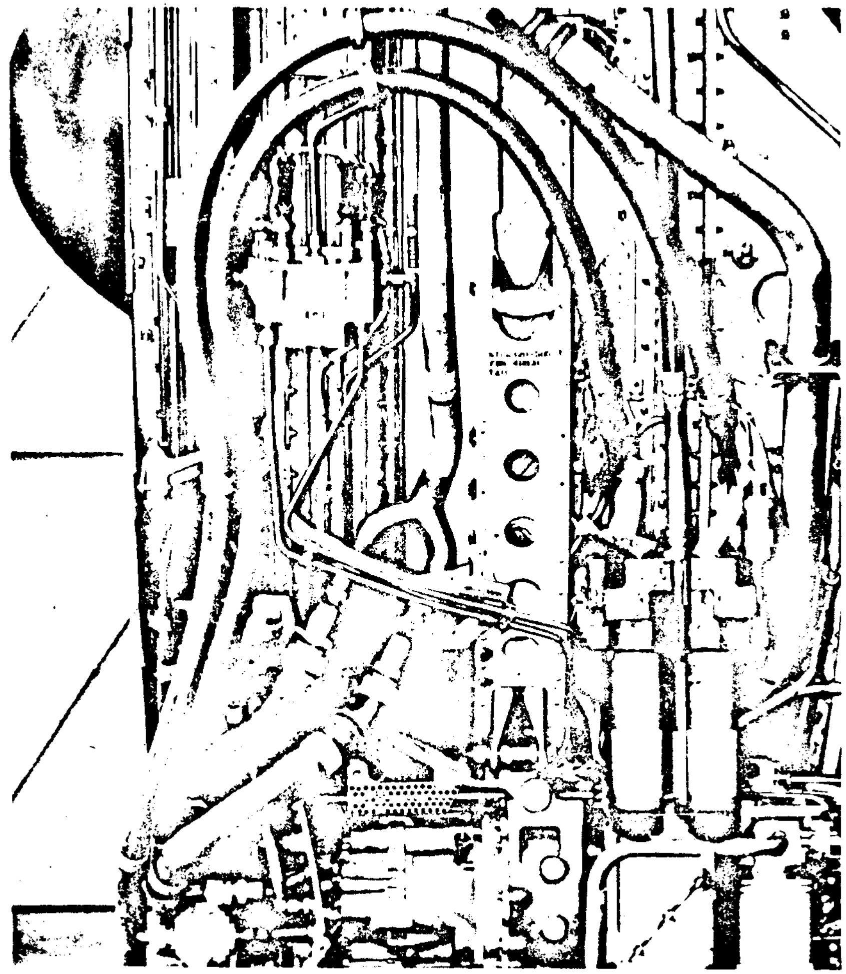


FIGURE 3-5. DC-10 PUMP PRESSURE LINES

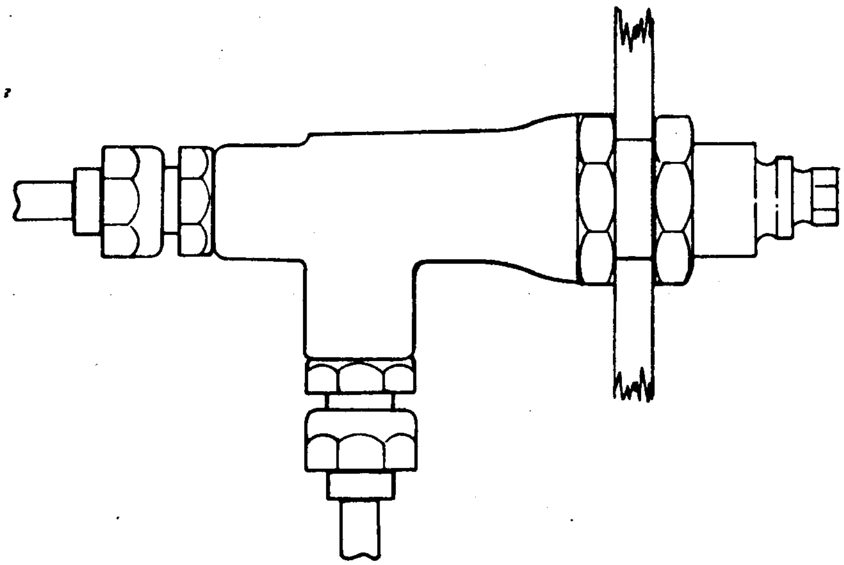


FIGURE 3-6. MANUAL SHUTOFF VALVE

valve, it may rotate in the service panel. This could deform the tubing and loosen the tube fittings. This is a generic problem and could very well occur on both hydraulic systems at one time.

The recommended correction is very simple. A small metal plate which bears against the flat of the valve body hex and is riveted to the service panel would prevent valve rotation. In addition, the jam nut should be lock-wired in place. These two things will prevent valve rotation and resulting tube deformation and leakage.

3.3.2.2 Orbiter Power and Utility Systems — The assessment of the Orbiter power and utility systems included a review of all components and lines in the power and utility systems with the exception of the water spray boiler and the nose gear steering. Data were not available for a review of these two items. Information on the water spray boiler has now been received and it will be reviewed at an early date. Servo actuators were reviewed as a group and are not included in the power and utility section discussion.

Many potential failures could not be considered a Criticality Category 1 condition because the effect of a single failure was confined to one power system.

Four situations exist in the Orbiter power and utility systems where a single failure may result in a Criticality Category 1 condition. These problems result from (1) hydraulic fluid leakage and spills, (2) leakage of Freon into hydraulic fluid, (3) failure of brakes as a result of tire blowout or thrown tread, and (4) external leakage at the brake control valve module.

3.3.2.2.1 Hydraulic Fluid Leakage and Spills — External hydraulic leakage is a problem that has existed in airplanes for many years. The best of modern systems used in current wide-bodied transports are a great improvement over those used in earlier aircraft. This is the result of improved fitting designs, better joints between lines and fittings, and increased use of permanent methods for joining tubing such as brazing, swaging, and welding. External leakage on the major three wide-bodied transports (DC-10, B747, and L-1011) is about the same in spite of their use of different detail hardware. Leakage is still a problem even with the best available technology.

Figure 3-7 shows a manufacturing tool for development of the hydraulic power systems on Orbiter Bulkhead 1307. The bulk of the equipment for three power systems is mounted here. There is little separation of systems and many small areas have lines and components from all three systems. This means that a catastrophic event such as a turbine explosion or a fire could result in the loss of fluid from all three systems. There are also many opportunities for leakage in this small space. The three systems should be separated, each to its own area, and barriers should be used to prevent fire or high-velocity debris from crossing from one area to another.

The design technology used in the Orbiter hydraulic power system components and lines is equivalent to that of current wide-bodied transport aircraft. The vibration environment in which the systems operate is much more severe than that of the aircraft. Also, the long periods in orbit even at lower pressure have a potential for the occurrence of failure. Therefore, it seems reasonable to assume a somewhat higher incidence of leakage will occur than in current transport aircraft.

The Rockwell International (RI) hydraulic system Schematic Drawing VS70-580997 shows several instances where a reducer fitting makes a very large change in a line size. One case has a 3/8-inch-diameter line teed into a 1-1/4-inch-diameter line. In this situation, the small line is very likely to fail since the mass of the fitting and large line forces the small line through large vibratory amplitudes and soon causes fatigue failures. This problem has resulted in a standard design practice at Douglas Aircraft Company — change line diameters a *maximum* of two standard line sizes. On the DC-10, the hydraulic lines are made of Armco 21-6-9 stainless steel tubing, but similar criteria for titanium lines and fittings should be generated for the Orbiter.

The RI schematic also shows the pump case drain line connected to a return line. The return line may experience high momentary flows that cause a rise in pressure sufficient to burst a pump case. This can occur in spite of the check valve which may not close fast enough to protect the pump. This situation has occurred on earlier Douglas airplanes and it is now standard practice to connect pump case drain to the reservoir with a dedicated line. This condition should be evaluated in the hydraulic system test program.

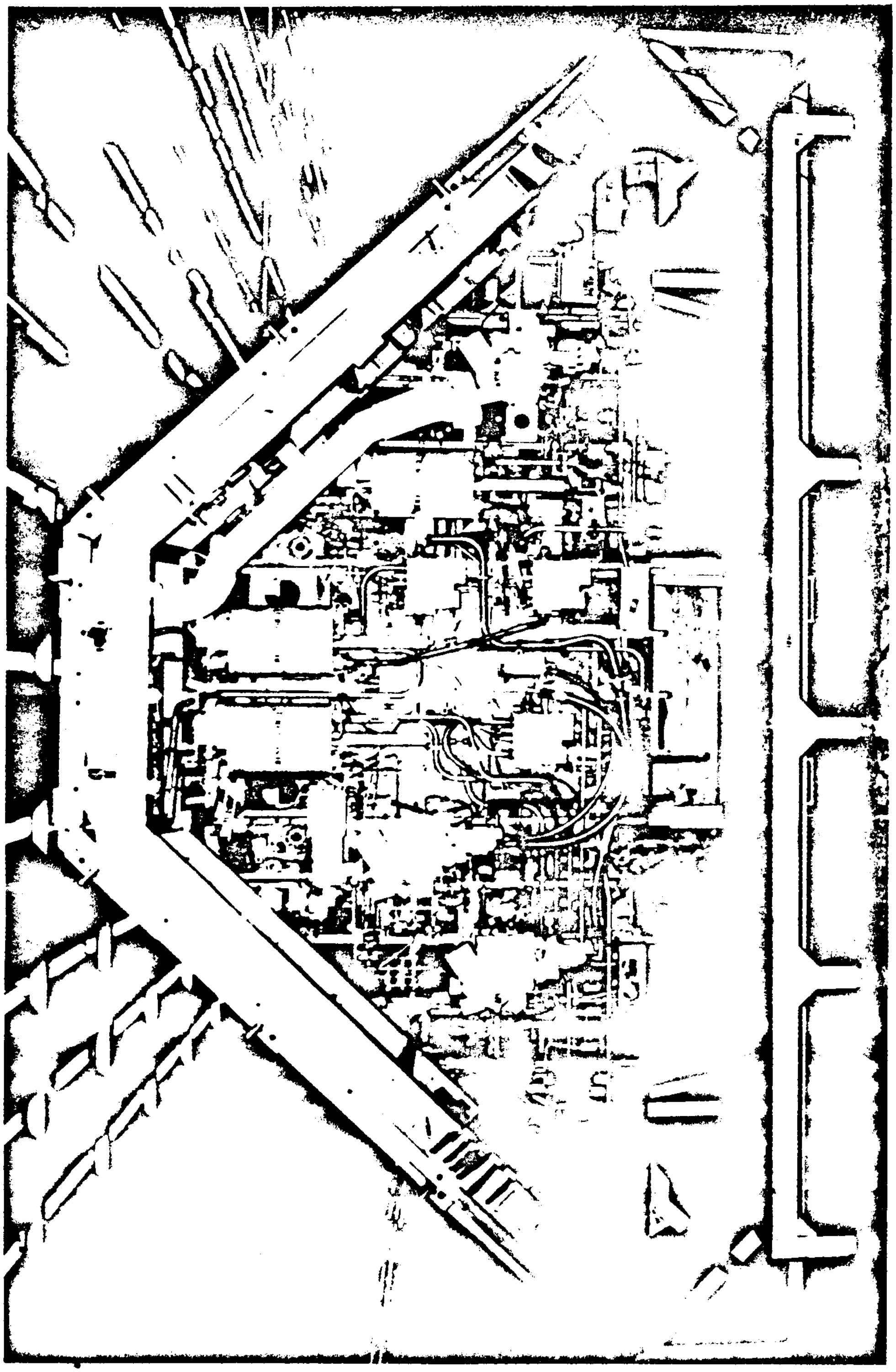


FIGURE 3-7. ORBITER STATION 1307 DEVELOPMENT FIXTURE

Based on what occurs in transport aircraft and the review of the Orbiter hydraulic system design, the following things probably would be causes of leakage.

1. Pressure surges and pump pressure ripple caused by:

   - Rapid valve closure
   - High flow surges in return line
   - Hydraulic resonance in pump pressure line

2. Vehicle vibration causing:

   - Abrasion of lines against lines or structure
   - Fatigue of small line at reducer fittings having large line-size difference
   - Loosened fittings

3. Lines not properly matched at installation

4. Servicing mishaps and large oil spills

3.3.2.2.1.1 Loss of Thermal Protection System (TPS) Tiles – External leakage can seep through skin joints and soak the TPS tiles which are porous. Tests have been made which show that a tile can absorb 700 to 800 percent of its dry weight in oil. Hydraulic oil does not affect the bond joint strength. However, during ascent the high vibration environment combined with the greater mass of a soaked tile can cause bond line load to exceed its strength capability. Some tiles may fall off during ascent. The critical condition occurs during reentry where the prior loss of a tile can result in a catastrophic primary structure failure from aerodynamic heating. (This condition is discussed in NASA report V9ES-135 dated January, 1978.)

The TPS tiles are coated on the sides to prevent absorption of moisture. On the inboard face, the tiles are bonded to a Nomex felt pad. NASA-JSC has suggested that these coating materials may act as a barrier against hydraulic fluid. The capability of the materials to survive multiple reentries and permit breathing or outgasing during ascent while still acting as an effective barrier against moisture and hydraulic fluid are essential characteristics. This possibility should be investigated.

3.3.2.2.1.2 Fire Hazard – The pump for each hydraulic power system is independently driven by a hydrazine-fueled hot gas turbine. There are hot spots on the turbine and its exhaust pipe that expose up to 1000°F surface temperatures. RI has proposed coating the auxiliary power unit (APU) and its exhaust pipe to prevent the ignition of hydrazine at 500°F. This treatment may also prevent hydraulic fires, but lack of detail information prevents making a positive statement. Hydraulic fluid has an autogenous ignition temperature of 650°F and a flash point of 400°F. A hydraulic leak could be a solid stream of fluid, a spray, or a fog, depending on the line pressure and the shape and size of the leak. It appears that well-atomized hydraulic fluid in a low-altitude air environment could cause an explosion with APU surface temperatures at 500°F.

According to RI, it was not possible to treat a 2-1/2-square-inch aperture at the gas generator "well" area, and as a consequence exposed surfaces exceeding 500°F will exist. RI has proposed that this condition be considered an "acceptable risk" for hydrazine. The problem evaluation and its proposed solution are reported in the following two documents:

1. APU Hydrazine Hot Surface Ignition Evaluation, TSR, January 1978.
2. Rockwell letter to Johnson Space Center, 78MA1885 dated April 19, 1978.

It is suggested that the 2-1/2-square-inch aperture at the gas generator injector well might be protected by a device based on the principle of a Davy's miner's lamp. One or more screens could be used. This approach could not be evaluated because of lack of data on the gas generator injector.

The problem of hydraulic fire or explosion should be evaluated in parallel with the proposal made for the control of hydrazine fires.

3.3.2.2.1.3 Hydrazine Line Insulation — A third problem is associated with the effects of wetting hydrazine line insulation with hydraulic oil. The insulation blankets are a fibrous material covered on one side with a thin, stainless steel foil. These blankets cannot be sealed because the change in atmospheric pressure would rupture an unvented cover. The hydrazine line blankets may therefore have spots wet with hydraulic fluid. The hydrazine lines incorporate thermal sensors which automatically control electrical line heaters. By these means the lines are intended to maintain a minimum temperature of 55° to 65°F in a cold environment.

If a segment of the hydrazine line insulation is wet with hydraulic fluid, that portion will have a higher thermal conductivity and therefore a lower temperature than other parts of the line. If this occurs adjacent to a thermal sensor, it will call for more heat and other parts of the line will exceed 150°F, the maximum allowable hydrazine temperature. On the other hand, if a wet spot exists away from a thermal sensor, that point will go below 35°F, the freezing point of hydrazine, and with a frozen plug of hydrazine, the APU could not be started. Either of these two conditions is unacceptable.

These problems are described in the following documents:

1. NASA Memorandum ES3 4-11/77-204M, November 22, 1977.
2. Rockwell International internal letter SEH-ITA-77-262, November 22, 1977.

3.3.2.2.1.4 Recommendations – Many things can be done to minimize the incidence of leakage and to provide protection from its effects.

There should be a special inspection of the hydraulic system in addition to all the inspections now required. It would be directed toward hydraulic leakage alone, and for this reason may reveal problems not already found. This is occasionally done at Douglas to solve a particularly troublesome problem. This inspection should check for proper fit of lines by loosening tube supports and fittings to see if lines have been forced into position at installation. The spacing of line support should be checked, along with the minimum clearance between lines and structure or other lines. This may be done by using a wood dowel as a "go" gage to verify proper clearances.

In view of the high vibration environment, tube fittings, caps, plugs, and bolt heads or nuts should be lock-wired.

The hydraulic system test program should evaluate the magnitude of pressure surges and pump pressure ripple. These things may be caused by rapid closure of valves and resonant conditions in lines. Problems of this kind can normally be detected only with high-response pressure transducers such as the Kistler gage which are capable of good fidelity up to about 10 kHz.

The flow of external hydraulic leakage should be controlled and directed to points where it does no harm. Oil leakage onto TPS tiles can be minimized by sealing around skin rivets and skin lap joints with a bead of sealant. This is done to seal pressurized compartments in transport aircraft, and it can be done after the structure is completely assembled. TPS tiles should be coated or sealed to prevent the absorption of hydraulic fluid. The cement used for their attachment to structures should also act as a hydraulic fluid sealant. Leakage flow can often be directed to sumps, overboard drains, and containers. There should be procedures which are rigorously followed for cleaning up accidental spills during servicing and for inspecting the TPS tiles for contamination.

The APUs and hydrazine line insulation should be protected from hydraulic leakage and sprays. This could be done with shields which protect these items from jets or sprays of hydraulic fluid.

Failures of the main engine turbine pumps have been reported. In the event that turbine blades were not contained, they could damage the SSME actuators and hydraulic lines and the body flap valve module and lines. The APU turbine has also failed in tests. Although the turbine blades were contained, the housing was cracked. This appears to be a marginal condition with respect to turbine blade containment. Components and piping on Bulkhead 1307 are vulnerable to flying debris. Efforts to ensure containment of parts for both of these turbines are continuing. To avoid catastrophic failures in the hydraulic power system, it is also important to provide protection for local areas where piping for all three systems converge.

3.3.2.2.2 Leakage of Freon Into Hydraulic Oil — A Freon heat exchanger is provided to warm the hydraulic fluid. It has a brazed plate and fin core with a welded sheet metal case. The single heat exchanger has independent and physically separated passages for each of the three hydraulic power systems. Two independent Freon pumping systems supply warm Freon 21 which passes adjacent to all three hydraulic chambers. Freon pressure is 320 psia maximum and hydraulic pressure is 150 psig maximum.

The construction of the heat exchanger involves many welds joining sheets of corrosion-resistant steel ranging from 0.046 to 0.079 inch thick. These joints are vulnerable to failure in a high vibration environment. The failure of a single welded joint would leak Freon into only one of the three hydraulic power systems. However, the Freon would eventually reach flight control and utility actuators and in some cases areas downstream of switching valves. There, the Freon 21 could attack Buna N seals since the two are an "unsatisfactory" combination. Such a failure of an external downstream of a switching valve could dump the hydraulic fluid from a primary system and its backup system. This can produce a Criticality Category 1 condition.

NASA-JSC personnel have indicated that a change to another type of Freon which is compatible with Buna N seals is not possible because of thermodynamic constraints. Likewise, changing all hydraulic seals is not a practical solution.

There is a second problem associated with Freon leakage. In the range of temperatures (110° to 275°F) and pressures (25 to 115 psia) that exist at the main pump and circulation pump inlets, Freon 21 is either a wet or superheated vapor. This means that very small concentrations of Freon 21 would cause mild pump cavitation. Large amounts would cause major cavitation or pump starvation because of vapor lock. Major amounts of vaporized Freon would also drive hydraulic oil out of the reservoir and exhaust it overboard. The effect of Freon on servocontrol performance is unknown. Because the pump cavitation effects of a single leak are confined to one hydraulic power system, they are not Criticality Category 1 items. They should nevertheless be evaluated.

3.3.2.2.2.1 Recommendations — No vibration test is called for on the Freon heat exchanger during production acceptance testing. Such a test should be specified. It would help to reveal which heat exchangers are apt to fail in a real pressure and vibration environment.

The effect of various mixtures of Freon 21 and hydraulic fluid on Buna N packings should be evaluated over the range of operating temperatures. This should establish a time factor for packing life. In addition, the effect of various Freon mixtures on pump cavitation and servocontrol performance must be evaluated.

Finally, the hydraulic fluid should be periodically analyzed to determine whether Freon leakage was occurred and, if so, to determine its extent. This type of sampling should be done before and after the first flight and at less frequent intervals if the experience is good.

3.3.2.2.3 Landing Gear Braking System – Once the Orbiter has touched down, vehicle deceleration is accomplished by a set of brakes on each of the four wheels in the main landing gear. The braking system is designed to operate on multiple hydraulic power systems for redundancy. It also incorporates an antiskid system to attain optimum braking effort. Each hydraulic system contains a pressure reducer valve to provide 1500 psi to each brake system manifold. Displacement limiting valves are provided so that a fluid leak at any point downstream of the brake control valves will be limited. See Figure 3-8 for a schematic drawing.

Certain types of failures in the brake actuation system in the wheels, in the brake control valve, and in the brake fluid lines can result in a Criticality Category 1 condition. These failures can result in a loss of all of the braking effort on one main landing gear or half of the effort on the entire vehicle brake system.

All of these types of failures impair the Orbiter's ability to stop. Based on ongoing analysis and tests of the braking system by NASA, it is possible that certain brake failure modes may result in serious vehicle problems. These are:

1. With no brakes on one wheel (two chamber sets inoperative), the Orbiter may overrun the runway at KSC.

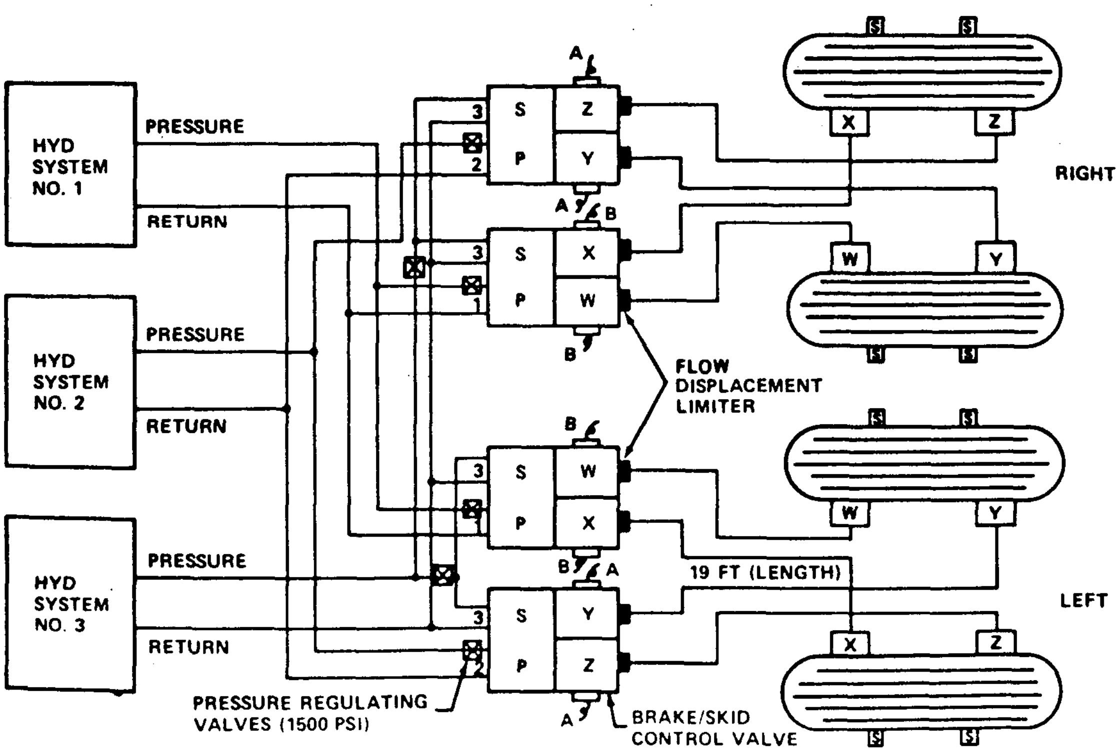


FIGURE 3-8. WHEEL BRAKE SUBSYSTEM

2. If Systems 1 and 3 or 2 and 3 are lost as a result of a single failure in the brake control valve, only half of the brake chambers are effective. With a 32,000-pound payload and the brake application started at 174 knots, the braking distance will probably be excessive.

It is recommended that the probability of hydraulic power supply failures be minimized. These problems are described in the following paragraphs with suggestions for limiting their occurrence. The analysis of brake failures and their effect on stopping distances should be continued. Finally, if stopping distance is a problem, alternative methods of stopping the Orbiter should be evaluated. These might include parachutes, arresting cables, or the like.

3.3.2.2.3.1 Failure of Brakes as a Result of Tire Blowout – On each of the two main landing gears, the four hydraulic lines to the brakes are located on the aft side of the shock strut. If a tire should blow out or a tread come loose on landing, a piece of tread could destroy all four lines. This would leave one landing gear with no brakes. The unbalanced braking and the reduced braking capability will affect directional control and may cause the Orbiter to overrun the end of the runway.

It is recommended that two brake lines be located on the forward side of the shock strut and two on the aft side. A set of dummy torque links can be used to support the forward brake hoses (see Figure 3-9). This is consistent with separation of redundant systems and is the configuration used on commercial transport aircraft.

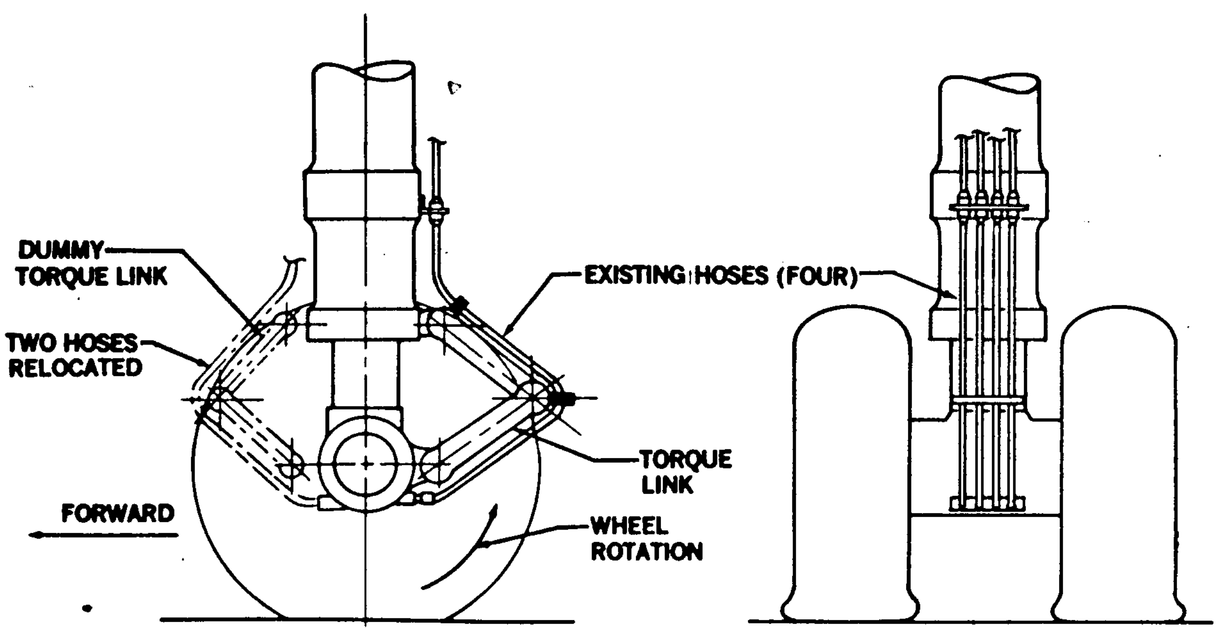


FIGURE 3-9. MAIN LANDING GEAR HOSE LOCATION

3.3.2.2.3.2 External Leakage at Brake Control Valve Module – Each main landing gear has two brake/skid control valve modules. Each module is connected to a primary (P_1) and a standby (P_S) hydraulic power system. Each module incorporates inlet filters, pressure-operated bypass valves, a switching valve, control valves, flow displacement limiter valves, outlet filters, and pressure transducers. A schematic drawing of this valve is shown in Figure 3-10.

An external leak downstream of the switching valve but upstream of the flow displacement limiter valves could dump all the fluid from both the primary and standby hydraulic power systems. This would be a Criticality Category 1 failure. It would adversely affect the performance of the flight control system. In addition, only half of the normal braking effort might be available. All of this could occur only after the landing gear shutoff valves were opened.

The following single point failures can cause the problems noted above:

1. The brake manifold is a proprietary design and only limited examination of the drawing was possible. There are many internal drilled passages in the manifold which contain Lee plugs. Loss of these plugs or substantial leakage past them between the switching valve and the flow limiter in either pressure or return passages could result in the loss of P_1 and P_S.

   Recommendation:

   - Add backup locks to ensure plug retention and a leakage barrier. Provide a rip stop design on the valve housing.

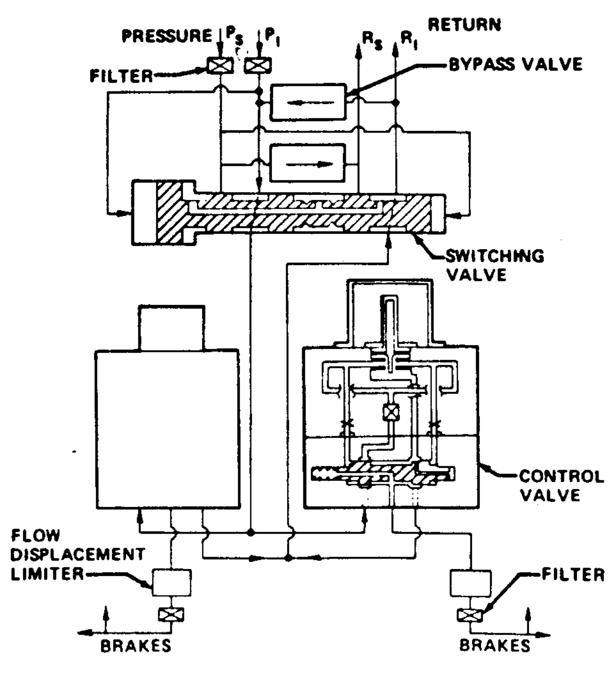


FIGURE 3-10. BRAKE VALVE MODULE

2. In the brake switching valve, there are seals on either side of the brake control valve chamber (see Figure 3-11). A failure of either seal will not be detected since there is normally no pressure difference across them. If there is a ruptured line in P_1 or P_S, the failure of the adjacent seal will permit fluid in the brake control valve chamber to be leaked overboard. This will result in a loss of both P_1 and P_S hydraulic power systems.

   Recommendation:

   - Provide check valves at each inlet to the brake control valve module (preferred, cost-effective).
   - Reduce the diametral clearance between switching valve sleeve and its housing. This barrier may reduce leakage to an acceptable level.

3. It was observed that threaded port plugs were locked with Long-Lok inserts. It is questionable whether these locks will remain effective for the 10-year service life of the operational system. Loss of these plugs could result in the loss of the P_1 and P_S systems.

   Recommendation:

   - Lock-wire all external plugs and caps.

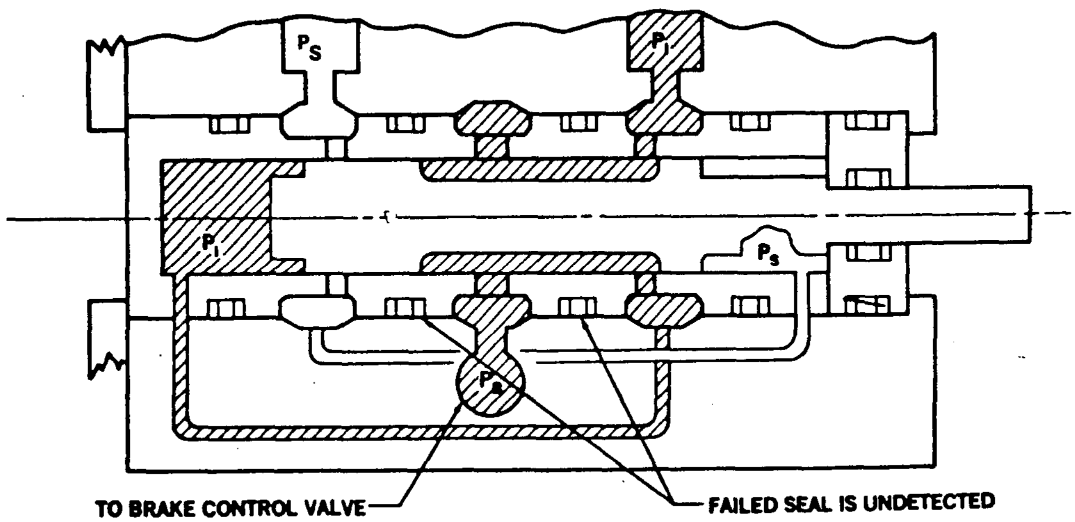


FIGURE 3-11. BRAKE/SKID CONTROL SWITCHING VALVE

3.3.2.3 Secondary Problems – This section is concerned with secondary problems which do not lead to Criticality Category 1 conditions but nevertheless can contribute to poor performance or failure.

3.3.2.3.1 Pump Delivery – The hydraulic pumps for the Orbiter are controlled by RI Specification MC281-0029. The D-01 Amendment to this document changed the rated rpm to 3918 from 3804. In Table I on Page 9 of this specification, the rated flow at Condition II was left unchanged. To maintain the original volumetric efficiency (98.63 percent) but still reflect the increased rpm, the rated flow in Table I, Condition II should be 68.3 gpm. The gain of 2.0 gpm should not be lost. Corresponding changes should be made in the Abex pump test documents.

3.3.2.3.2 Oil/Freon Heat Exchanger – The oil/Freon heat exchanger is used to warm hydraulic fluid during orbit. It is a moderately compact unit and is mounted on the left-hand side wall of the fuselage 5 feet aft of Bulkhead 1307. The heat exchanger is divided into three compartments, one for each of the three hydraulic power systems. This configuration presents a condition of vulnerability to a single event which could sever lines for all three hydraulic power systems. To provide maximum protection against a single catastrophic event, the heat exchanger should be divided into three units which would then be located at three widely separated points. This is in accordance with the principle of separation of redundant systems.

3.3.2.3.3 Water Spray Boiler – Three water spray boilers, one for each hydraulic power system, are located at the top centerline of the fuselage just aft of Bulkhead 1307. The three units are mounted parallel to each other with a minimum amount of clearance between them. This condition is the same as for the oil/Freon heat exchanger with regard to the vulnerability of all three hydraulic power systems to damage by a single catastrophic event. For the same reason, the water spray boilers should be physically separated from each other to minimize multiple failures.

3.3.2.3.4 Single External Seals – Most of the components which make up the power and utility systems appear to have been designed to conventional aircraft criteria. For the most part, this poses no problem. However, because the Orbiter environment is more severe than that of normal aircraft, the likelihood of external hydraulic leakage appears greater. This might have been minimized by using either dual external seals or a close-fitting metal barrier in series with a single seal. Such a change would be difficult to justify at this time. This concept should be considered for future design activities.

3.3.2.3.5 External Tank Retract Actuator Hoses – There are six external tank retract actuators. Each is connected to a fluid power system with two hoses. Each hose has a conventional B-nut connector on one end and a swivel fitting on the other. The way in which all 12 hoses are installed involves application of torque to the B-nut connector as the actuator moves. This could loosen this fitting over a period of time. If the ends of the hose were reversed with the swivel end next to the actuator, the torque on the B-nut end would be greatly reduced. The hose ends are not physically interchangeable with their mating fittings so this cannot be done without changes in the actuators and connecting tubing.

3.3.3 SERVOCONTROL SYSTEMS ASSESSMENT

Single Failure Point (SFP) Criticality Category 1 and 1U failure modes were investigated for the servocontrol hardware associated with the Space Shuttle. The following items were assessed:

1. SRB TVC actuators
2. SSME TVC actuators
3. Elevon actuators
4. Rudder/speed brake hydraulic control module
5. Body flap hydraulic control module
6. Main engine fuel control valve modules.

Seven areas of concern became apparent in the assessment:

1. Jammed spools
2. Loss of mechanical feedback bias springs
3. Failure of internal hydraulic seals
4. Failure of external hydraulic seals
5. Actuator piston rod bearings/packing glands
6. Hydraulic motor brake failure
7. Actuator strength criteria.

Each of these concerns is addressed in the following paragraphs.

3.3.3.1 Jammed Hydraulic Valves — The Space Shuttle's servocontrol hydraulic actuators/modules use slide valves which can be jammed due to contamination. If this occurred, there would be loss of life and loss of the vehicle. A jammed power valve in the elevon, rudder/speed brake, or body flap is a SFP resulting in a Criticality Category 1 condition. In addition to the power valve, the lock valve is also a SFP on the SSME TVC actuators. The SRB TVC actuators have three valves that can jam — the power valve, the lock valve, and the switching valve. If any one of the valves jams, a Criticality Category 1 or 1U condition results.

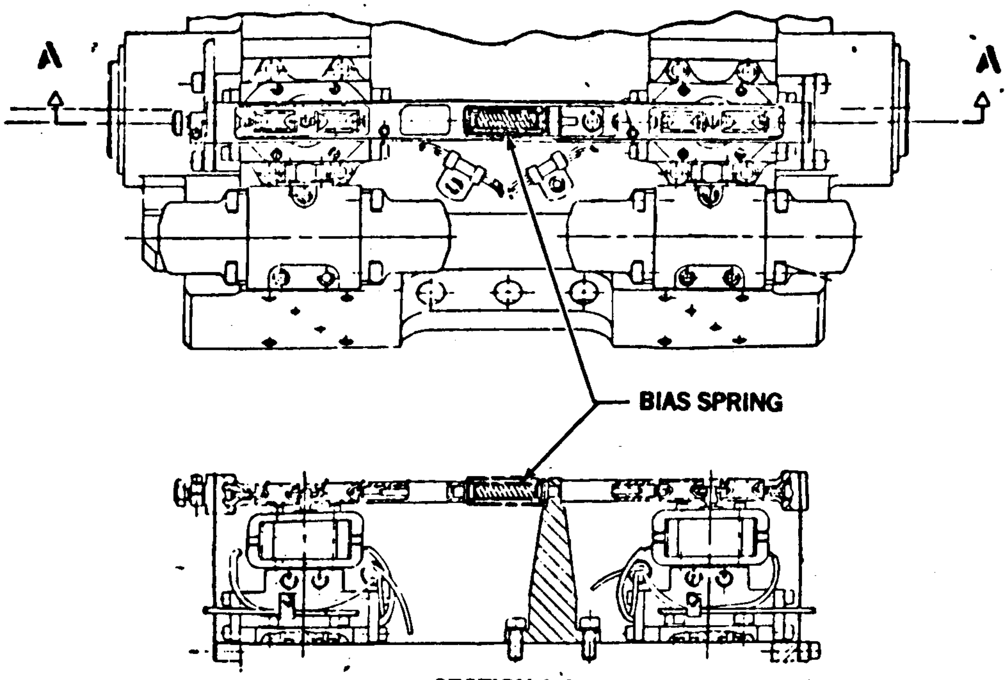
A stuck power valve will cause the actuators or hydraulic motors to drive their respective control surfaces into a hardover position. The lock valve on the TVC actuators, if jammed, will not hold the actuators in their last command position after supply pressure is lost. The single switching valve on the SRB TVC actuator, if jammed, will not switch to allow the standby pressure source to come on-line if the primary pressure source fails. The lock valve and the switching valve failure modes are classified as Criticality Category 1U since these failures are undetected and are not apparent until the first failure occurs — in this case, loss of supply pressure.

Large contaminant particles can be built into new, recently replaced, or overhauled hydraulic components. Particles may be generated due to a failure of a component or by being ingested directly when lines are opened for maintenance, etc. The high-vibration environment which the Space Shuttle generates at vehicle liftoff can put particles into circulation that are in the system but never flushed out. The large forces generated to overcome a jam by the differential pressures acting across a valve spool make it possible for the spool to shear through contaminants of a relatively large cross-sectional area. Even though this is the case, precautionary measures should be taken. It is recommended that a contamination screen be installed at each supply pressure servoactuator/hydraulic module inlet to prevent particles that can create a jam from entering the hardware. Contamination screens will prevent large failure-causing contaminants from jamming the critical SFP components. A fine filter, 10-microns nominal, 15-microns absolute, is still required in the servoactuator to protect the delicate hydraulic components and servovalves. The fine filter would be located between the coarse screen filter and the components susceptible to contamination by fine silt particles.

Redundant jamproof valves could be used to eliminate this failure mode; however, a jamproof valve is a rather complicated part. Since the power valve design is already made up of many parts, it is recommended that the present valve design which can generate large forces to drive through contaminants be combined with inlet screens as a practical solution for eliminating the problem of jammed spools. The screens should have sufficient area to minimize pressure loss but openings small enough to capture contaminants which exceed the shearing force of the valve spool.

3.3.3.2 Loss of Actuator Position Mechanical Feedback Bias Spring — The SRB TVC and the SSME TVC actuators use mechanical negative feedback of actuator position to each of the four channel servovalves to close the actuator position control loop. The mechanical feedback design uses a bias spring to hold the hysteresis to a minimum by preloading the linkage in one direction. The spring is unrestrained and could possibly vibrate off its supporting pivots. Loss of control of two servovalves will result if this occurs. A force fight will take place between the two remaining servovalve channels and the two malfunctioning servos. As a result, loss of control of the actuator and vehicle will occur. This is a SFP resulting in a Criticality Category 1 condition. The spring in question is identified by Moog Drawing No. A05769. It is installed on the SRB and SSME Moog power valve assemblies (Figure 3-12). The spring should be positively caged to prevent the unit from jumping out of position and causing a critical malfunction.

This problem was reported to NASA-MSFC and NASA-JSC and corrective action is being taken.



SECTION A-A

FIGURE 3-12. ACTUATOR POSITION MECHANICAL FEEDBACK BIAS SPRING INSTALLATION

3.3.3.3 SRB TVC Actuator Piston Head Internal Hydraulic Seal Failure – The SRB TVC actuator piston head seal (Figure 3-13) is a dynamic seal with the actuator control pressure applied across the seal. A failure of the seal can allow internal leakage in excess

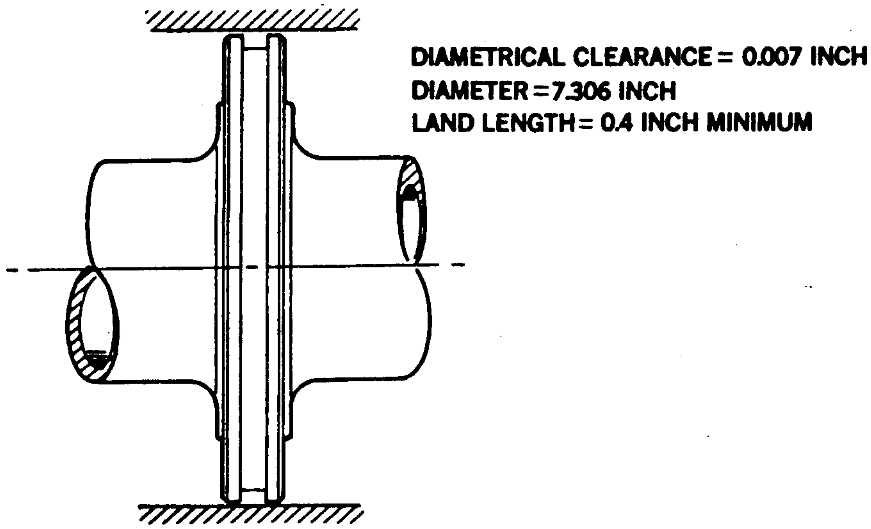


FIGURE 3-13. SRB-TVC ACTUATOR PISTON

of 20 gpm to occur. This would create a Criticality Category 1 condition since loss of control of the actuator and vehicle would occur.

MSFC conducted annulus flow tests from which the curve in Figure 3-14 was plotted. The test specimen had a diameter of 1.74 inches at the annulus, with an 0.005-inch

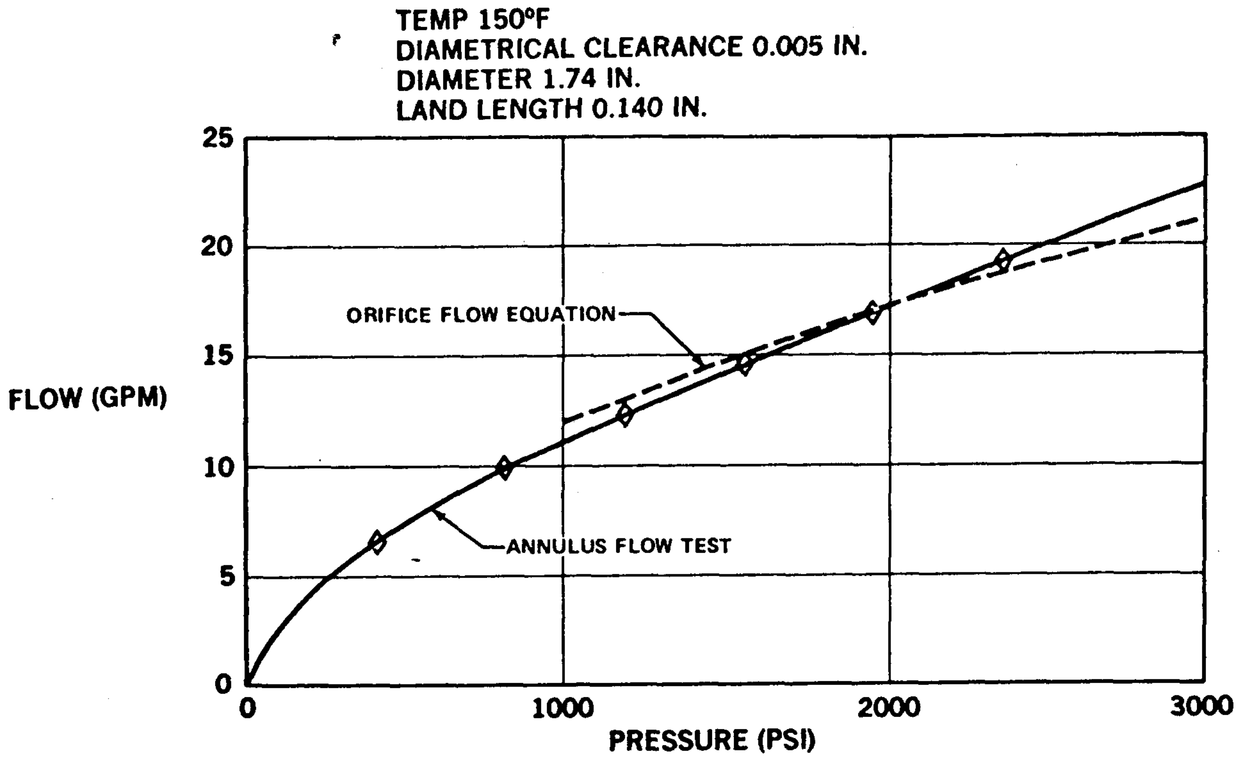


FIGURE 3-14. MSFC ANNULUS FLOW TESTS

diametral clearance, a land length of 0.14 inch, and a measured hydraulic fluid flow of 17.3 gpm at 150°F with 2000 psi applied across the lands. The piston head seal has a diameter of 7.31 inches with an 0.007-inch diametral clearance and a land length of 0.4 inch. The actuator piston seal area through which the leakage flow passes has increased from 0.01367 to 0.08037 square inch. The flow through the opening is directly proportional to the area and inversely proportional to the land length. The leakage flow past the piston head seal with the seal completely removed equals 35.6 gpm as extrapolated from the MSFC leakage flow test results for a differential pressure of 2000 psi applied across the lands.

$$Q_2 = Q_1 \times \frac{A_2}{A_1} \times \frac{L_1}{L_2} = 17.3 \text{ gpm} \times \frac{0.08037 \text{ in.}^2}{0.01367 \text{ in.}^2} \times \frac{0.14 \text{ in.}}{0.40 \text{ in.}} = 35.6 \text{ gpm}$$

Hydrazine is used to power the APU which drives the hydraulic pump. Any hydrazine in excess of that required to provide pressurized hydraulic control fluid for gimballing the SRB thrust vector nozzle at 3 deg/sec and for operating the four servovalves per control actuator can be used to provide leakage flows for any malfunctioning hardware. The extra hydrazine on board can accommodate a 20-gpm internal leak for the entire ascent portion of the SRB-powered flight. Since failure of the actuator piston seal causes an internal leakage flow in excess of 35 gpm, loss of actuator control will occur.

A recommended fix is to install a barrier metallic piston ring seal in series with the existing seal as was done for the Space Shuttle elevon and the SSME TVC actuator piston head seal.

3.3.3.4 SRB TVC Transient Load Relief Valve External Hydraulic Seal Failure — An analysis was made of the seals in the revised transient load relief valve, Moog Drawing No. A23010. The study revealed that Seal No. 1 (Figure 3-15) had a leakage rate of 3.1 gpm with a differential pressure of 2000 psi applied across the lands with the seal failed. A Criticality Category 1 failure condition exists because the leakage rate is above the maximum allowable rate of 2 gpm. The 2 gpm flow limit is equivalent to the volume of hydraulic fluid in two SRB reservoirs that can be lost during vehicle ascent before the TVC hydraulic control system becomes inoperative. An annulus flow equation for laminar flow was used to calculate the leakage past a 100-percent failed seal (see Figure 3-16).

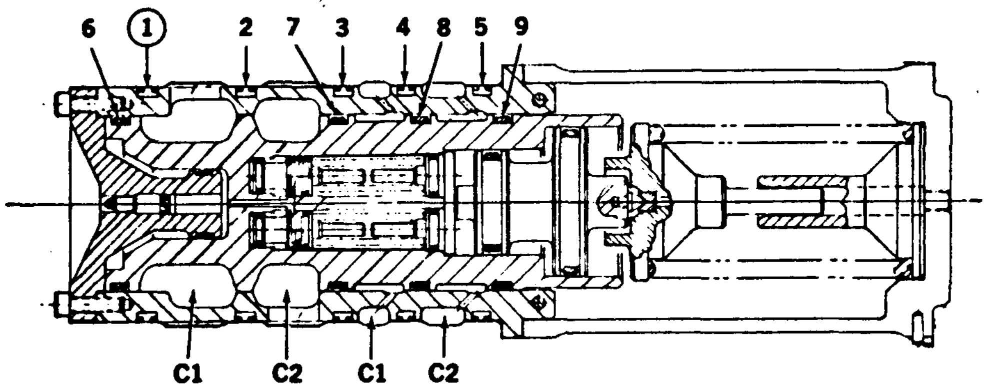


FIGURE 3-15. SRB TRANSIENT LOAD RELIEF VALVE

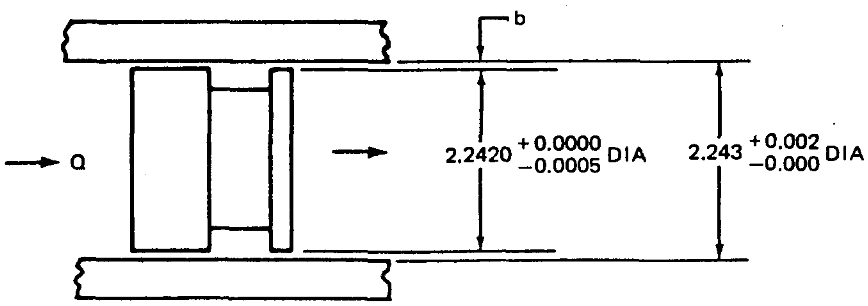


FIGURE 3-16. VALVE ANNULUS DIMENSIONS

$$Q = \frac{\pi D b^3}{12\mu L}\left[1 + 1.5\left(\frac{\epsilon}{b}\right)^3\right](P_u - P_d)$$

where

Q = steady flow in annulus between shaft and cylinder = 11.97 in.^{3}/sec = 3.1 gpm

D = diameter of passage = 2.243 in.

b = passage height = 0.00175 in. (worst case)

μ = fluid viscosity = 1.146 x 10^{-6} lb-sec/in.^{2} at 150°F

L = passage length = 0.587 in. (worst case)

ϵ = eccentricity of circles = 0.001 in. (due to eccentricity of seal groove)

P_u = upstream pressure = 2000 lb/in.^{2} (control pressure)

P_d = downstream pressure = 15 lb/in.^{2} (actuator cavity pressure)

NASA-MSFC ran a flow leakage test on a seal configuration with a passage length of 0.565 inch, a diameter of 1.74 inches, and a diametrical clearance of 0.001 inch at 150°F. With the seal removed and 1500 psi applied across the lands, a leakage rate of 1.1 gpm was measured. Using the annulus equation with this set of conditions, the Q was calculated to be 0.69 gpm. The eccentricity was assumed equal to 0.001 inch. The annulus equation gave lower leakage results than the test. Using the test results of 1.1 gpm and extrapolating this flow for the actual set of parameters used in the flight valve produces a flow of 9.6 gpm.

$$1.1 \text{ gpm} \times \frac{(b_f)^3}{(b_t)^3} \times \frac{D_f}{D_t} \times \frac{L_t}{L_f} \times \frac{(P_u - P_d)_f}{(P_u - P_d)_t} =$$

$$1.1 \text{ gpm} \times \frac{(0.00175)^3}{(0.001)^3} \times \frac{2.243}{1.740} \times \frac{0.565}{0.587} \times \frac{2000}{1500} = 9.6 \text{ gpm}$$

where subscript "f" is for flight hardware and subscript "t" is for test hardware.

It appears the leakage flow could be as much as 9.6 gpm. The leakage rate is calculated to be excessive by either extrapolating the test results or using the annulus flow equation. To reduce the leakage flow, a barrier seal should be provided, the passage length increased, or the annulus between the housing and outer bushing decreased. This problem was reported to NASA-MSFC. Corrective action is being taken by providing a barrier seal. Updated drawings showing the corrective action taken have not been provided to this assessment team.

3.3.3.5 SRB TVC Switching Valve External Hydraulic Seal Failure – The SRB TVC actuator switching valve has two seals, No. 2 and No. 3 (see Figure 3-17), which are considered single failure points and are classified as having a Criticality Category 1U failure mode. A 1U category is an undetected failure that requires a second failure to occur before the undetected failure becomes critical to the vehicle and crew. A failure in Seals 2 and 3 would be undetected since primary and standby system supply pressures exist on both sides of the seals. Any difference in pressure between the two supply pressures will cause a small flow of fluid from one system to the other since system pressures would not be exactly identical. This will cause reservoir levels to change slightly during the 144-second APU operating time in ascent. If standby supply pressure is lost and Seal 2 fails prior to the loss of standby pressure, then the primary pressure will be lost with hydraulic fluid flowing across the failed seal and overboard through the standby system leakage failure point. Likewise, if Seal 3 fails and an external leak occurs in the primary supply, then the standby supply will be lost after the valve spool transfers, allowing the standby fluid to pass through the failed seal and overboard through the failed primary supply leakage path. Actuator control is not lost if only the primary hydraulic system is lost; however, with an undetected seal failure that allows the loss of the standby system, then the crew would lose control of the actuator and vehicle.

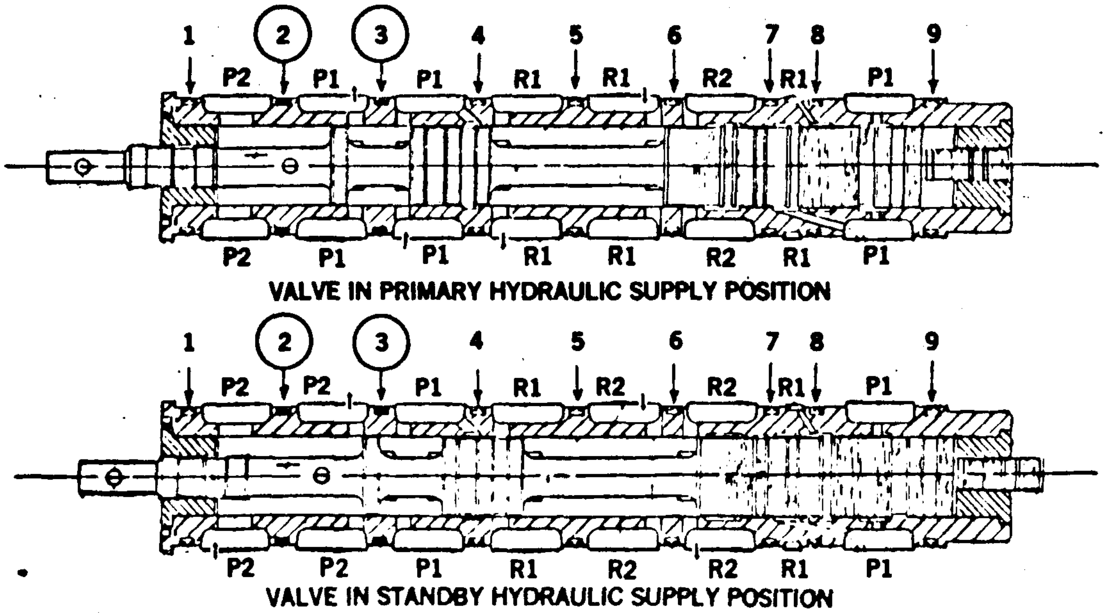


FIGURE 3-17. SRB-TVC SWITCHING VALVE

A failed seal allows an external leakage flow rate of 23 gpm. The maximum allowable on the SRB is 2 gpm. An external leakage flow greater than 2 gpm will drain the primary and standby hydraulic reservoirs, thus losing gimballing control of the booster for the remainder of ascent flight. MSFC ran seal failure leakage tests, and the test data are presented in Figure 3-14. The test specimen characteristics and test conditions are those of switching valve Seals 2 and 3. Extrapolating the leakage flow tests to a differential pressure of 3000 psi across the lands produces a leakage flow rate of 23 gpm.

3.3.3.6 SSME TVC, R/SB, Elevon Servo Valve Face Seal Load Relief – Moog servo valve face seal leakage test data indicated that a failed supply pressure seal would leak fluid at the rate of 1.99 gpm.* The maximum allowable external leakage flow on the Orbiter is 0.1 gpm. This leakage flow would drain one reservoir during entry. A failed seal would allow fluid to seep across the mounting face of the servo valve, opening up the face slightly to reduce the effect of the barrier. A fix was made by undercutting a major portion of the mounting face (Figure 3-18), thereby reducing the buildup of force. The material left provided a tighter barrier to reduce the leakage flow. The item was left open until test data are received indicating the fix has reduced the leakage flow to 0.1 gpm or less.

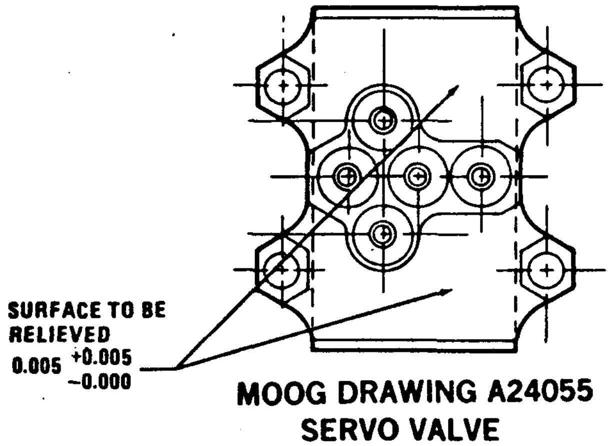


FIGURE 3-18. SERVO VALVE FACE SEAL LOAD RELIEF

3.3.3.7 SSME TVC, R/SB, Elevon Filter Differential Pressure Indicator – Moog seal leakage test data revealed that a failed seal caused excessive leakage to occur from under the filter differential pressure indicator mounting face. The housing is a purchased part made of AL2024-T3 aluminum. The seepage of fluid from under the aluminum flange would deform the flange, reducing its ability to function as a fluid barrier. A fix was made by clamping a steel plate across the top of the housing (Figure 3-19) to provide a solid backup to the flange in order to prevent the flange from deforming. This item was also left open until test data indicate that corrective action has reduced the leakage to 0.1 gpm or less.

*Elastomeric Seals Study for The Space Shuttle Main Engine TVC Servoactuator, Moog Report E-2299, Page 29, dated December 3, 1976.

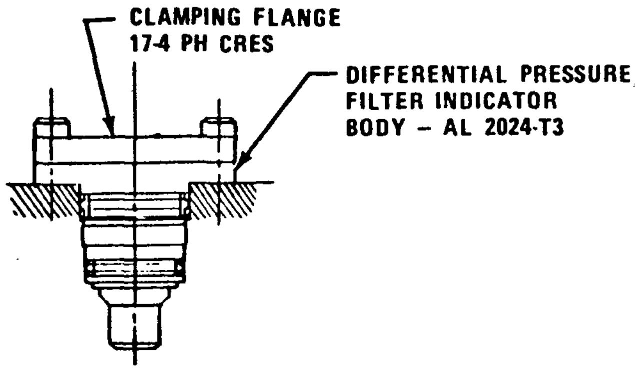


FIGURE 3-19. FILTER DIFFERENTIAL PRESSURE INDICATOR BARRIER SEAL

3.3.3.8 Failure of Rudder/Speed Brake Switching Valve Manifold Union T-Seals – Four unions (Moog Drawing No. A23797) called for in the hydraulic valve module assembly Drawing No. A23830 (see Figure 3-20) are used to transfer hydraulic supply pressure fluids from the switching valve manifold to the rudder power valve manifold, and an additional four unions are used to transfer supply pressure fluids from the switching valve manifold to the speed brake power valve manifold. Primary supply pressure is transferred through two of the unions; first and second standby supply pressures are transferred through the two remaining unions of the four unions per mounting face.

A T-seal failure on one of these unions would allow supply pressure to seep between the manifolds, enlarging in area until the fluid finds its way overboard from between the

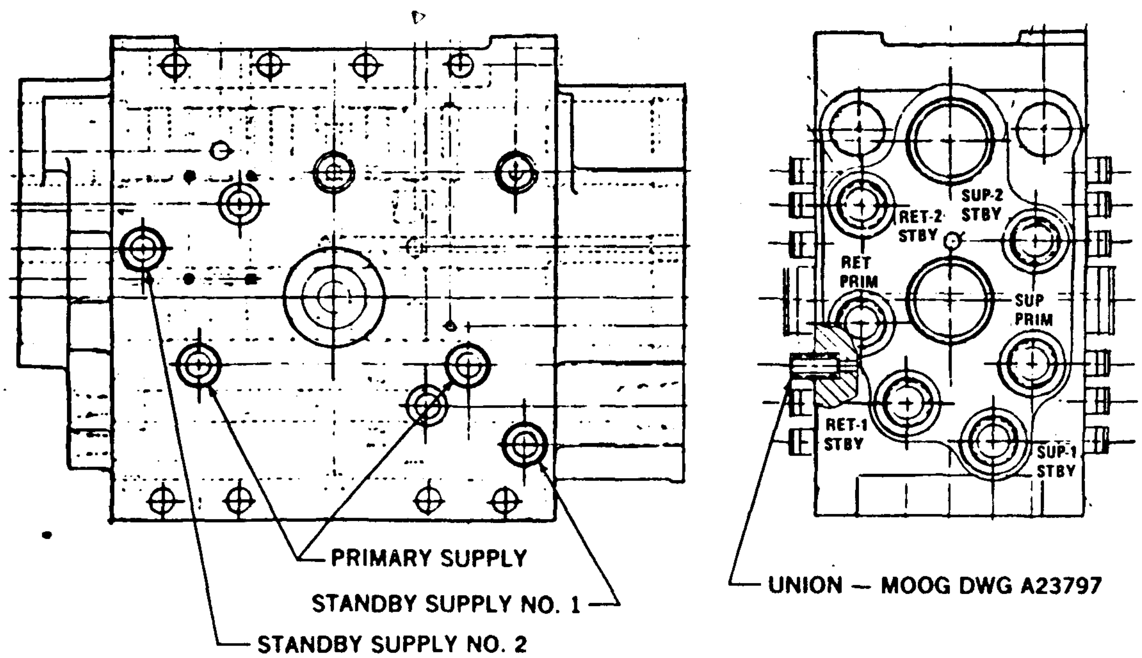


FIGURE 3-20. R/SB SWITCHING VALVE MANIFOLD AND UNIONS

manifold assemblies. The fluid released between the manifolds and under pressure will build up a load attempting to force the manifolds apart. It is possible to lose the three hydraulic supplies if the bolts holding the manifolds together rupture, causing a malfunction of all servo control modules and actuators. These seals are single failure points resulting in a Criticality Category 1 condition in which loss of the vehicle occurs. There are 16 SFPs. If the pressure were to build up to 3000 psi under one-fourth of the mounting face area, and four of the eight 3/8-inch-diameter bolts were resisting the load, then a bolt failure could occur. Each bolt would be required to hold 9413 pounds, whereas the bolt yields at 7594 pounds at 275°F; thus, the bolt margin of safety drops to −0.19.

It is recommended that a union seal leakage test be made to determine the adequacy of the design. It is recommended that load relief be provided as was done in the case of the Orbiter servovalves – example Moog valve, Drawing No. A24055 – by undercutting the surface to prevent load buildup between the manifolds which could cause bolt failure and loss of three hydraulic systems.

This problem was reported to NASA-JSC and corrective action is being taken by undercutting the mounting face to provide load relief. No updated drawings have been provided to this assessment team.

3.3.3.9 Actuator Piston Rod Bearings/Packing Glands – The SRB TVC, SSME TVC, and elevon actuators use two piston rod bearing packing glands per actuator that are shrunk-fit into position (see Figure 3-21). No positive restraint of the bearings or packing glands is provided. Douglas uses positive locking of their piston rod bearings on

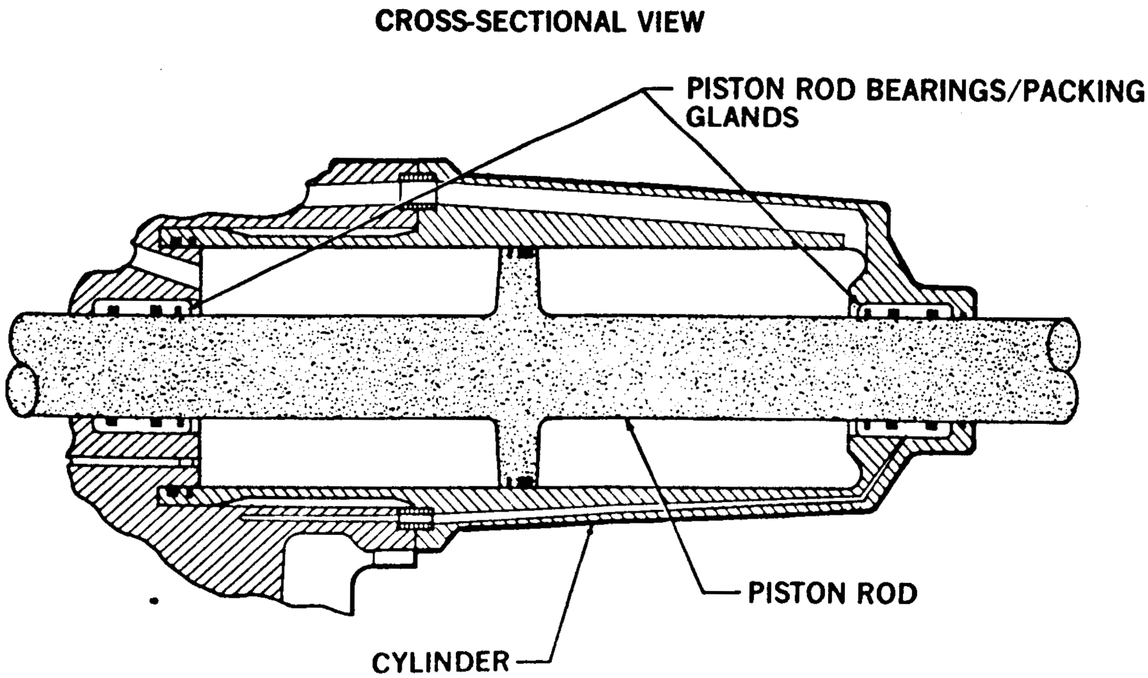


FIGURE 3-21. ELEVON ACTUATOR

flight control actuators. If the Space Shuttle piston rod bearings became unseated, then a massive external leak would occur. Since the single failure point is downstream of the actuator switching valves, all hydraulic systems would be lost overboard. It is recommended that the design call for positive locking of the piston rod bearings, thus eliminating 28 SFPs.

3.3.3.10 Hydraulic Motor Brake Fails in Off Position – The rudder/speed brake and body flap hydraulic control modules respond to electrical command signals to position a power valve which controls the flow of fluid to three independent hydraulic motors. The output velocities of the three hydraulic motors are mechanically summed through two differentials into a single output shaft to provide a drive into a mechanical mixer in the case of the rudder/speed brake and to the control surface in the case of the body flap. A hydraulic brake is employed at the output shaft of each hydraulic motor that is operated off the motor system pressure. At a predetermined decaying pressure, the brake is engaged to maintain the last commanded position of the control surface with no motor inputs and to prevent any torque from feeding back to the motor.

If a motor brake fails in the off position, then the two remaining motors will cause the failed system to run in reverse. This type of failure will cause loss of the vehicle, and is classified as Criticality Category 1U. It is an undetected failure and does not become apparent until after the supply pressure is lost. The body flap brake may be applied as often as two times per second; thus, many operational cycles can be applied to the hardware. A failure of the brake piston (Figure 3-22), pressure plate, or spring will prevent the brake from operating properly.

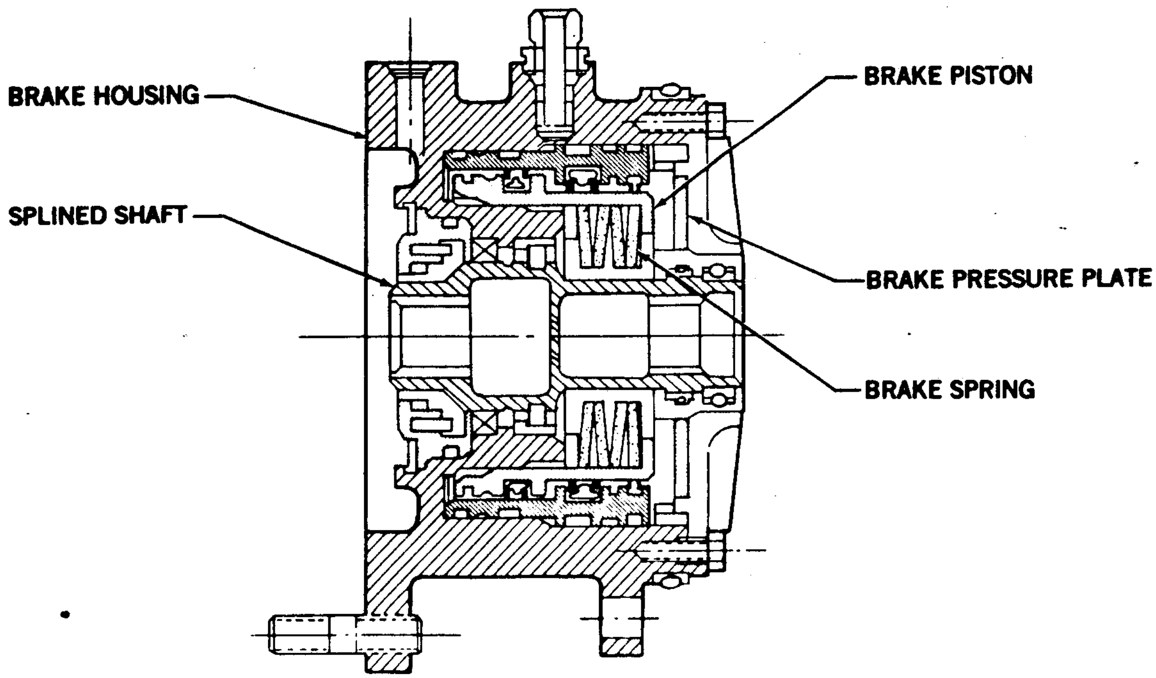


FIGURE 3-22. HYDRAULIC MOTOR BRAKE ASSEMBLY

Successful life cycle testing of the brake is required to increase the chances of success; however, the brake is a single failure point and it is recomended that a backup braking device be implemented for the body flap as well as for the rudder/speed brake configuration.

The rudder/speed brake (R/SB) design connects the hydraulic control module with the motors through a section of steel tubing. This provides an additional single failure point. A slow fluid leak in the tubing may not reduce the pressure enough to allow the brake to be applied; however, its motor may be driven in the reverse direction by the output of the other two motors and as a result, loss of control may occur with a resulting loss of life and the vehicle. This type of failure is classified as Criticality Category 1.

3.3.3.11 Actuator Strength – As a part of our assessment, we reviewed superficially the strength analysis reports for an elevon and SSME TVC actuator. The reports were examined to see if appropriate procedures, load factors, and safety margins were evident. Several items appeared to be questionable and further investigation was conducted. The questionable areas found were as follows:

1. Criteria for primary flight controls do not satisfy the minimum requirements set forth in the FAA airworthiness standards.

2. Calculated stresses shown are not always the maximum stresses the parts will experience.

3. The Fracture Control Plan has not been completely implemented.

3.3.3.11.1 Commercial Aircraft Design Philosophy – Commercial aircraft must comply with FAA document airworthiness standards: Transport Category Airplanes, Part 25. Of particular interest are Paragraphs 25.671 (C1, C2, and C3) which are quoted below:

25.671 Control Systems

> (c) The airplane must be shown by analysis, test, or both, to be capable of continued safe flight and landing after any of the following failures or jamming in the flight control system and surfaces (including trim, lift, drag, and fuel systems), within the normal flight envelope, without requiring exceptional piloting skill or strength. Probable malfunctions must have only minor effects on control system operation and must be capable of readily counteracted by the pilot.

(1) Any single failure, excluding jamming (for example, disconnection or failure of mechanical elements, or structural failure of hydraulic components, such as actuators, control spool housing, and valves).
(2) Any combination of failures not shown to be extremely improbable, excluding jamming (for example, dual electrical or hydraulic system failures, or any single failure in combination with any probable hydraulic or electrical failure).
(3) Any jam in a control position normally encountered during takeoff, climb, cruise, normal turns, descent, and landing unless the jam is shown to be extrmely improbable, or can be alleviated. A runaway of a flight control to an adverse position and jam must be accounted for if such runaway and subsequent jamming is not extremely improbable.

FAA airworthiness standards require a dual load path for all primary flight control actuators unless a single failure can be demonstrated to cause only minor effects on the control system operation.

Douglas policy has been to qualify even a fail-safe actuator by life-cycle endurance testing to three lifetimes for commercial aircraft and four lifetimes for military aircraft.

During the preliminary design phase, large factors on stress are used depending on the required cycles per lifetime.

Basically, the purpose of a fatigue analysis is to aid in the design of the individual components in order to minimize the number of parts that would require modification during the endurance verification test program. Generally, fatigue analysis is not acceptable for safe life structure unless a factor of 3 is used on stress. This may result in high margins of safety when the final static stress analysis is performed. The ultimate load used for analysis is based on the higher of 1.5 x 3850 psi (full flow relief valve pressure) or 1.5 times the pressure developed from the maximum load anticipated in one lifetime (as when gusting is encountered during a maneuver).

3.3.3.11.2 Moog Report DR No. SE06, Elevon Structural Analysis – The finite element stress analysis using program SAP IV or SAP V is a very good approach and is much better than Roark.* However, the centroidal stresses shown through most of the report are not the maximum stresses. The outer surface stresses should be used and care taken to assure that the proper element edge represents the outer fiber. Edge stresses could be as much as two times the centroidal stresses. The only uses of edge stresses in this report are discussed on Pages 6 and 61 of the Moog report.

Trapezoidal elements should be used in the high stress intensity areas and not triangular elements for the axis-symmetrical option. Reentrant corners (e.g., radii at the bottom of O-ring grooves) should be modeled with four or five elements from tangent point to tangent point, even for radii as small as 0.020 inch.

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*SAP - A Structural Analysis Program developed by the University of Southern California, Dept. of Civil Engineering, Los Angeles, CA 90007.

More analyses of the more complicated nonsymmetrical areas of the aluminum body and stainless steel cylinder should be done using Type 5, 3-dimensional solid elements or Type 8, thick shell and 3-dimensional elements of SAP IV or SAP V.

Use of SAP IV or SAP V finite element analysis would help identify the high stress intensity areas for the fatigue analysis that is lacking in this report. The only fatigue calculation in this report is found on Page 6. We believe that a thorough fatigue analysis would reveal a number of fatigue-critical areas. The high-stress-intensity areas should be identified by conventional fatigue analysis and good engineering judgment.

3.3.3.11.3 Actuator Fracture Control Plan — Fracture control verification is supposed to ensure that the maximum undetectable flaw within a part will not grow to a critical size and cause a fast fracture of the part within four lifetimes or less than four lifetimes if the part is replaced periodically.

Rockwell International (RI) has prepared a document, SD73-SH-0082A, entitled Space Shuttle Orbiter Fracture Control Plan, published September 1974. This document defines the criteria for analysis and tests needed to provide fracture control verification of hardware. Figure 3-23 taken from that document is a block diagram presenting the fracture-critical part selection logic. When applied to the control actuators, it states that normal static and fatigue analysis must be completed on a part. It also asks whether loss

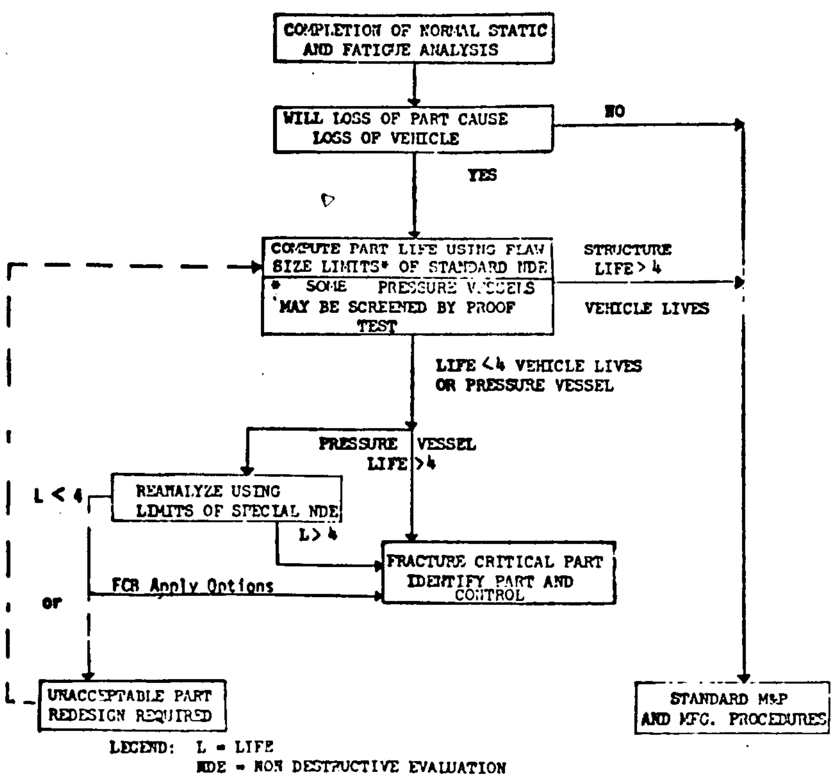

FIGURE 3-23. FRACTURE CRITICAL PART SELECTION LOGIC

of the part will cause loss of the vehicle. If the answer to this question is "no," then the part is made according to standard manufacturing procedures. If the answer to the question is "yes," then the Fracture Control Plan must be applied to the part.

In the case of the servocontrol actuators, the parts are single-load-path flight-critical items and, as such, the Fracture Control Plan must be applied to this hardware. The Fortress Program as applied to the actuators must include the Fracture Control Plan. The actuator fracture control verification effort has been deferred. This effort should have been accomplished during initial testing of the hardware; however, it is recommended that this verification effort be accomplished as soon as possible to minimize the impact of testing and any consequent changes in the hardware.

3.3.3.12 Summary — In summary, there are 291 single failure points discussed in the servocontrol systems assessment. Of this number, NASA has indicated that as of July 11, 1978, 196 are being subjected to corrective action. The remaining items are awaiting consideration. The SFPs identified in Section 3.3 have been summarized in Table 3-1.

TABLE 3-1
SINGLE FAILURE POINT TABULATION

	CRITICALITY CATEGORY	SRB-TVC	SSME-TVC	ELEVON	R/SB	B/F
1. JAMMED SPOOLS						
POWER VALVE	1	4	6	4	6	3
SWITCHING VALVE	1U	4				
LOCK VALVE	1U	4	6			
2. BIAS SPRING *	1	8	12			
3. PISTON HEAD SEAL	1	4				
4. TRANSIENT LOAD RELIEF VALVE *	1	4				
5. SWITCHING VALVE SEALS	1U	8				
6. SERVO VALVE FACE SEALS *	1		72	48	24	
7. FILTER OP INDICATOR SEAL *	1		6	4	2	
8. UNION SEALS *	1				16	
9. PACKING GLAND	1	8	12	8		
• 10. MOTOR BRAKE	1U				6	3
11. FRACTURE CONTROL	1	4	6	4	1	

*INDICATES NASA IS TAKING CORRECTIVE ACTION.

3.3.4 Hydraulic System Architecture Assessment

The assessment of the Space Shuttle hydraulic system architecture is divided into two sections. The Solid Rocket Booster (SRB) thrust vector control (TVC) actuation architecture is addressed in Paragraph 3.3.4.1. The assessment of the Space Shuttle Orbiter hydraulic system architecture is addressed in Paragraph 3.3.4.2. The calculations substantiating the architecture assessment are presented in Paragraph 3.3.4.3.

3.3.4.1 SRB TVC Actuation Architecture Assessment – The SRB TVC actuation system architecture basically consists of two hydraulic systems, one primary and the other available through a pressure-operated switching valve. This system, to operate an essential service for a short time, is consistent with commercial aircraft design practice except that the loss of one SRB TVC actuator package as a pressure vessel or a structural member creates a Criticality Category 1 condition.

3.3.4.1.1 Horsepower Requirements – Sufficient horsepower is available to produce the desired gimbal rate of 5 deg/sec for both servo actuators under normal operating conditions as presently defined; that is, with the present-size actuators, the existing pressure drop through the actuator package, and with both auxiliary power unit (APU) driven hydraulic power systems in operation (Paragraph 3.3.4.3.1).

The standby power provided by only one operative hydraulic system is adequate to provide a 3 deg/sec gimbal rate, providing an APU overspeed of 113 percent is attained, the internal leakage is not excessive at the time that standby power is required, and the hydraulic pump volumetric efficiency is not subnormal (Paragraph 3.3.4.3.2).

It is recommended that the APU overspeed operation be eliminated providing stable control can be achieved with a slightly reduced gimbal rate (Paragraph 3.3.4.3.3) as this simplifies the system and increases its reliability.

3.3.4.1.2 System Architecture – The SRB TVC actuation system architecture consists of two 3000-psi hydraulic systems. Each is powered by one 68-gpm variable displacement hydraulic pump driven by a separate, independent, hydrazine-fueled auxiliary power unit subsystem.

One hydraulic system supplies primary power to the tilt TVC actuator package and the other supplies primary power to the rock TVC actuator package. (See Figure 3-24.) In the event one of the systems fails to operate, either as a result of fluid loss due to external leakage or to an APU or pump failure, the other hydraulic system is used as a standby source of power through a pressure-operated switching valve in the affected TVC actuator package. No other standby power is provided. The SRB TVC actuation system operates for only 2 minutes after launch.

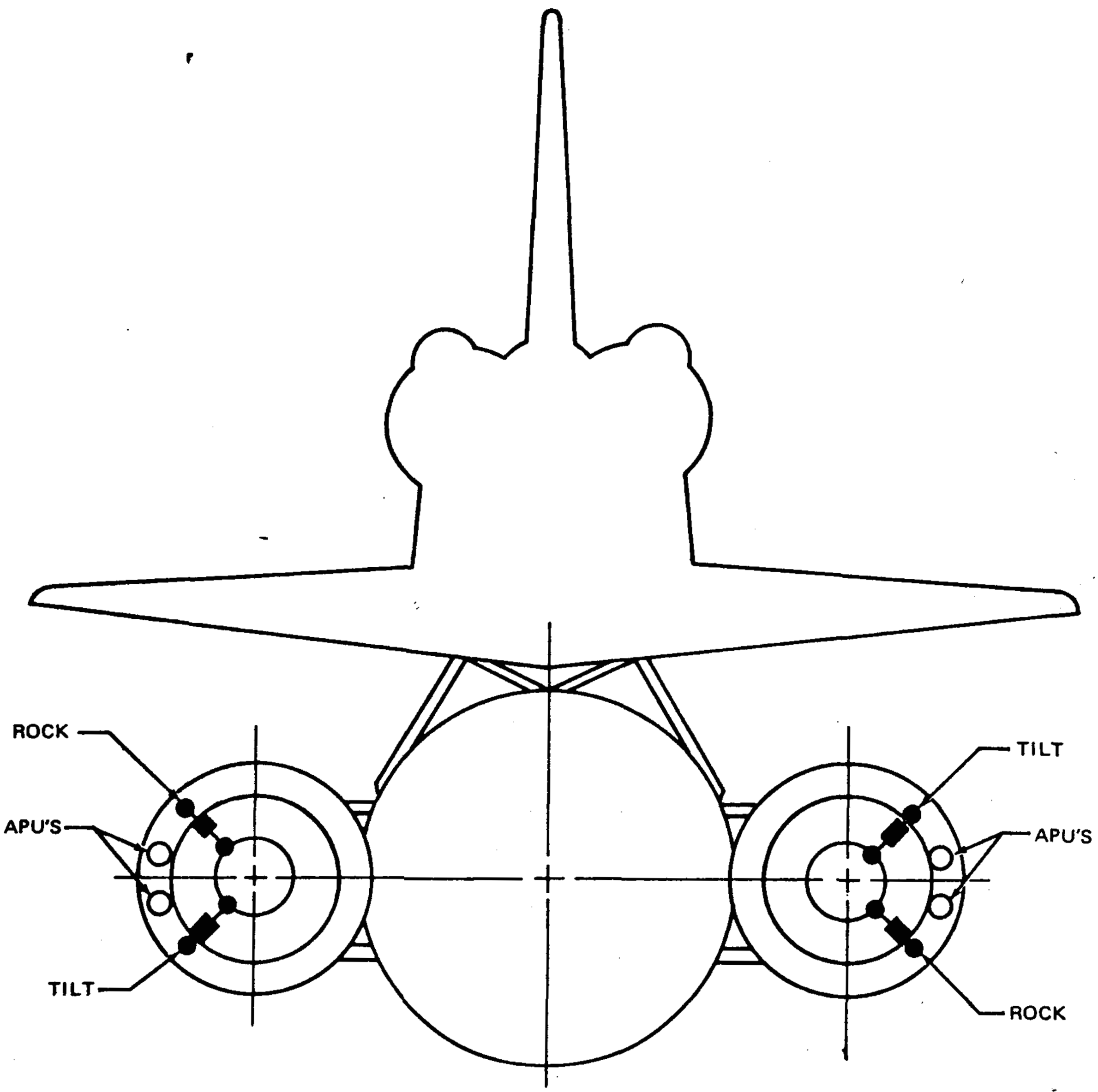

FIGURE 3-24. SOLID ROCKET BOOSTER THRUST VECTOR CONTROL ACTUATORS AND APU LOCATIONS

The concept of using two systems to supply power to a service which operates for only a limited time through a switching valve was applied for many years on braking systems on aircraft. This concept proved to be adequate when the switching valve design was carefully controlled to preclude malfunction. The operation of the SRB TVC actuator switching valves is a Criticality Category 1 item. Therefore, these valves must incorporate positive switching characteristics; i.e., it must be impossible for the valves to stick in the midposition and the filtration and switching forces must be adequate to ensure shearing of any possible contaminant that might lodge between the slide and sleeve. The valves must be designed so that an undetected failure will not cause loss of the second system when the first system failure occurs. For example, if a static seal was inadvertently omitted or damaged on the switching valve sleeve between the primary system pressure supply inlet and the pressure-to-actuator outlet, the second system would be lost following the actuation of the valve as a result of the failure of the first system.

Any pressure vessel type failure downstream of the switching valves in the SRB TVC actuator packages will cause both hydraulic systems to fail, which results in a Criticality Category 1 condition.

The rock and tilt actuator packages would be considered essential to flight if the normal commercial aircraft philosophy were observed, in which case a tandem actuator with a dual load path or some other means of providing redundancy would be employed if possible. The DC-10 aircraft incorporates multiple control surfaces to provide redundancy, eliminating the need for dual load path actuators. The B747 incorporates dual load path in some flight control actuator packages. A fortress type design has been used on commercial aircraft in the design of flight control actuator packages when space or weight limitations do not permit a redundant design to be used and the failure of the unit when so designed can be shown to be extremely improbable. The DC-10 aircraft incorporates fortress type designs.

The SRB TVC actuator packages are used for a limited time of 2 minutes immediately after launch. A gross external leakage greater than 2 gpm is required to completely drain both SRB hydraulic reservoirs in 2 minutes. Therefore, the actuator packages remain fully operative for the required 2 minutes, providing an external leakage greater than 2 gpm does not develop. Service records show that slow external leaks occur at least 10 times more often than gross leaks (greater than 1 gpm).

Considering the precedents set by aircraft braking system design, some usage of fortress type design in aircraft, and the SRB TVC hydraulic systems' tolerance to slow external leakage type failures, the existing design of the SRB TVC single actuator packages is marginally acceptable. A fortress program including a fracture control plan and superior quality control is needed.

The two-system concept is acceptable for this application because the systems are relatively simple and used for only a short time. This results in high reliability. Since only two systems are available, it is important that pattern failures are detected and eliminated. Therefore, hydraulic pump and system verification testing is required to substantiate the basic reliability of the systems.

The 2-minute use immediately after prelaunch and ground tests enhances the reliability of the entire SRB TVC actuator system. However, care must be exercised in specifying meaningful preflight and ground checks to ensure that the systems are operating as designed and that no undetected failures exist prior to launch. Both reservoir volumes should be monitored immediately before launch to determine if either system is leaking externally. The internal leakage and pump delivery of each system and the satisfactory operation of the switching valves including flow delivery should be tested immediately before launch. This may be accomplished by depressurizing one pump and then the other and observing in both conditions that the gimbal rate is 3 deg/sec. Then, to determine that the switching valves and the lock valves are fully open, both pumps should be pressurized and the gimbal rate should be observed at 5 deg/sec.

3.3.4.1.3 Summary – Basically, the SRB TVC actuator system architecture is consistent with commercial aircraft design practice. Sufficient horsepower is available to produce the desired gimbal rate of 5 deg/sec under normal operating conditions with the present actuator sizing. The standby power provided by only one operating hydraulic system is adequate to provide a 3 deg/sec gimbal rate providing there are no undetected failures in the operative hydraulic system and the APU subsystem responds to the 113 percent overspeed command when standby power is required.

3.3.4.1.4 Recommendations

1. The SRB/TVC system architecture as it is presently designed appears to be weight- and cost-effective. However, certain revisions in the servo actuators and hydraulic power system are suggested for implementation in other sections of this report.

2. Increased reliability and system simplification are possible by eliminating the APU overspeed operation after the failure of one hydraulic supply system if it can be shown that stable control can be achieved with a slightly slower than 3 deg/sec gimbal rate during ascent. This should be considered after sufficient testing has been completed to verify that a slower gimbal rate is acceptable.

3. Adequate ground and prelaunch test procedures must be prepared and assessed.

4. Hydraulic pump and system verification tests must be completed and evaluated.

3.3.4.2 Space Shuttle Orbiter Hydraulic System Architecture Assessment

3.3.4.2.1 Areas of Study – The Space Shuttle Orbiter hydraulic system architecture assessment considered evaluation of the existing hydraulic power supply and distribution arrangement, the horsepower requirements and system delivery, and the hydraulic designs for actuation of the Space Shuttle primary flight controls. These controls include the Space Shuttle main engine thrust vector controls (SSME TVC), the main engine controls (ME controls), the body flap (BF), hydraulic valves and motors only, the rudder/speed brake (R/SB) hydraulic power drive unit, and the elevons.

3.3.4.2.2 Hydraulic Power Supply – The current Space Shuttle Orbiter hydraulic system architecture is based on three redundant hydraulic systems. Each system is pressurized by one 3000-psi variable displacement (68-gpm maximum) hydraulic pump, each driven by a separate, identical hydrazine-fueled auxiliary power unit (APU) subsystem. It would be preferable for each system to have a dual pump power source and to be driven by different types of subsystems to achieve maximum redundancy and reliability. The pump loading on the Orbiter is such that maximum horsepower is required for standby operation. For this reason, another full-size hydraulic pump would be required to provide a dual power source for each system. The weight and cost penalties are not warranted by the additional redundancy achieved. In addition, Douglas concurs with NASA's evaluation of alternate driving subsystems in that it is impractical to develop a satisfactory one in the time allotted. Therefore, the existing hydraulic power supply system architecture is acceptable providing a superior design and inspection program is initiated to ensure the best possible APU subsystems are incorporated for driving the hydraulic pumps.

3.3.4.2.3 Hydraulic Power Distribution – The hydraulic systems provide power for operating the primary flight controls (i.e., the SSME TVC, the main engine fuel controls, the body flap (BF), the rudder/speed brake (R/SB), and the elevons), and the utility systems (i.e., the landing gear actuation, brakes, nose wheel steering, and external tank umbilical retraction).

The flight control hydraulic power requirements impose the greatest demand on the systems and dictate the basic hydraulic system architecture.

The concept of a three-hydraulic-system architecture to provide redundancy for the operation of fully powered flight controls has proven to be satisfactory on commercial aircraft. However, the required redundancy and reliability have been achieved by incorporating the following:

1. Standby power available without manual or automatic switching.

2. Independent systems to ensure that no single failure can cause loss of more than one system.

3. Adequate power in each system to ensure safe flight and landing with only one operable system.

4. High individual system reliability and confidence by careful design and selection of components with an extensive service history.

5. Redundant control surfaces so that loss of control of one surface will not cause the aircraft to be lost.

There are numerous single failure points (SFPs) downstream of the switching valves within the Space Shuttle Orbiter flight control actuator packages. These SFPs can cause loss of all three Orbiter hydraulic systems, which could result in loss of the Orbiter. These single failure points are pressure vessel failures which may result from a seal failure, a fractured housing, or a bolt or screw failure. Since a seal failure occurred early in the Orbiter program, the seal problem has been adequately treated by the use of redundant seals or seal barriers except as noted in Paragraphs 3.3.2 and 3.3.3 of this report. However, the problems of fractured housings and screw failures have not been adequately addressed. The Orbiter R/SB and elevon actuator packages have a multitude of components and manifolds that are held together by screws. Commercial aircraft service records show that the component housings, the manifolds with numerous drilled passages, and the actuators are all subject to fracture failures. Design and inspection of manifolds with numerous drilled passages is particularly difficult as stress risers are inherent.

Bolt and screw failures have also occurred in aircraft flight control actuator packages. These failures have resulted from overtorquing, undertorquing, bolt fractures, and not using lockwire when specified on the drawings. Since commercial aircraft are designed to fail operative/fail operative criterion, the fractured housing and bolt failures that have occurred have not been catastrophic. However, similar failures occurring in the Orbiter would result in loss of the Orbiter because the Orbiter actuator packages incorporate switching valves which automatically select one system after another. If the primary system fails, this would result in loss of all three hydraulic systems.

In this architecture assessment, an attempt will be made to indicate how the existing single failure points which may cause loss of all three hydraulic systems can be eliminated.

3.3.4.2.4 Horsepower — The selection of a three-system architecture for supplying redundant hydraulic power to operate aircraft primary flight controls implies that sufficient horsepower is available in each system so that safe flight and landing are possible by using any one of the systems when the other two are inoperative (FO/FS). However, it was determined that the system specification (SD72-SH-0102-6, Paragraphs 3.2.5.1 and 3.2.5.2) requires only fail-safe after the loss of one hydraulic system during the ascent mode and full operational capability for aerodynamic flight control functions during the descent mode. This philosophy does not seem valid unless it can be established that the reliability achieved with these requirements imposed is acceptable for the aerodynamic flight control functions.

During ascent, at least two operable hydraulic systems are required for engine throttle control. The existing design and procedures limit the ascent mode to 13.44-minute duration immediately after launch (the time lapse between launch, T = 0, and closure of the SSME hydraulic isolation valves). It is recommended that the SSME hydraulic isolation valves be closed as soon as possible which will shorten the time span of Orbiter vulnerability to single failure points during the ascent mode. System reliability is indirectly proportional to exposure-to-failure time. By shortening the exposure time from 13.44 minutes to about 8 minutes and improving the reliability of the critical actuator packages, the probability of the loss of two hydraulic systems during ascent becomes sufficiently remote that it is acceptable.

The critical actuator packages which require reliability improvement are those which have single failure points that could result in loss of two hydraulic systems during the ascent phase of flight. The ones affected are: (1) the SSME TVC actuator packages, (2) the R/SB hydraulic power drive unit (PDU), and (3) the elevon actuator packages. The recommended improvements are discussed in Paragraphs 3.3.4.2.5, 3.3.4.2.8, and 3.3.4.2.9.

The Orbiter should also be capable of safe flight and landing throughout the balance of the mission with only one hydraulic system operative. With the existing R/SB and elevon actuation designs, a horsepower deficiency exists during the approach and landing phases of flight. It is recommended that these actuator designs be improved to reduce the horsepower required during approach and landing, as discussed in Paragraphs 3.3.4.2.8 and 3.3.4.2.9. This is more weight- and cost-effective than increasing the horsepower delivery of each hydraulic system.

3.3.4.2.5 Space Shuttle Main Engine Thrust Vector Control (SSME TVC) Actuation – Single type servoactuator packages incorporating redundant switching valves drive the SSME TVCs on the existing OV102 Orbiter (Figure 3-25). Only two of the three hydraulic systems supply power to each SSME TVC actuator package. Therefore, an external leakage type failure downstream of the switching valves in an SSME TVC actuator package results in loss of only two hydraulic systems. The SSME TVC actuator packages operate only during the ascent phase of flight. Closure of the SSME isolation valves prevents loss of hydraulic fluid from the hydraulic systems as a result of a leakage type failure in the SSME actuation systems after ascent.

The existing procedures limit the time the hydraulic system is vulnerable to loss of fluid as a result of an external leakage failure in the SSME TVC system to 13.44 minutes immediately after launch (it is recommended this time be shortened, if possible). An external leak of about 1.5 gpm will drain two hydraulic system reservoirs in 13.44 minutes. The SSME TVC actuators would remain operative during ascent even if a slow external leakage failure (less than 1 gpm) developed in one of the SSME TVC actuator packages. Probably two of the three hydraulic systems would remain operative after closing the SSME isolation valves. This is in contrast to the fact that a slow external leakage in either the rudder/speed brake hydraulic power drive unit or an elevon actuator package downstream of the switching valves can drain all three reservoirs and result in loss of all three hydraulic systems.

Aircraft service records indicate gross external leakage failures (greater than 1 gpm) occur less than one-tenth as often as slow external leakage failure. Since a gross external

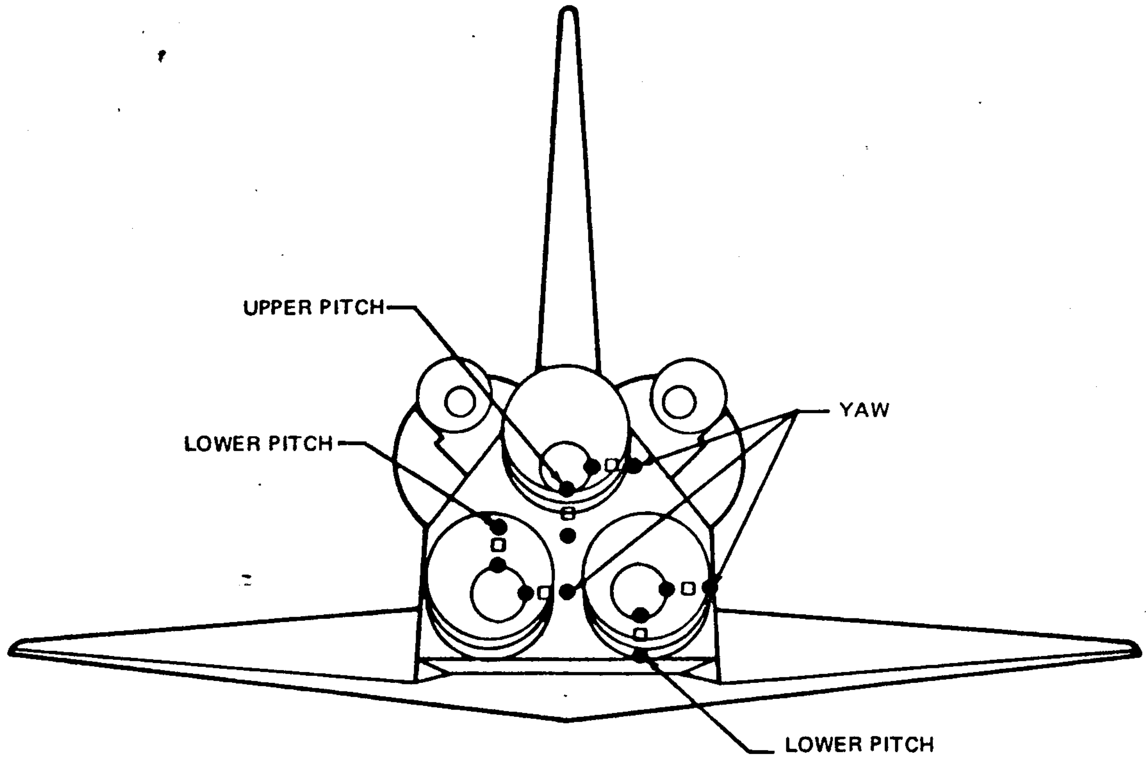

FIGURE 3-25. ORBITER MAIN ENGINE THRUST VECTOR CONTROL ACTUATOR LOCATIONS

leakage failure must occur before the SSME TVC actuator packages become a Criticality Category 1 item, these units are less critical than either the R/SB PDU or the elevon actuators, and the existing single type SSME TVC actuator packages are marginally acceptable for use on the operational Space Shuttle Orbiter.

It is recommended that a fortress type program be implemented. This program should include a fracture control plan, a review to ensure optimum design, and superior quality control methods.

3.3.4.2.6 Main Engine Fuel Control Actuation – A different hydraulic system is used to supply power to each main engine fuel control. Therefore, any single failure in a main engine fuel control hydraulic subsystem will not cause loss of more than one hydraulic system. A main engine hydraulic system isolation valve is installed in each hydraulic system and is used to shut off fluid flow and pressure to the main engine fuel control and SSME TVC actuation subsystems after ascent is completed. The existing main engine fuel control actuation architecture is acceptable for use on the operational Space Shuttle Orbiter.

3.3.4.2.7 Body Flap Hydraulic Actuation – The three redundant hydraulic systems are completely separated in the existing body flap hydraulic operating subsystem design. No single failure can cause loss of more than one hydraulic system. The only single failure points in the body flap hydraulic actuation system are a hydraulic brake failure or a valve jam. Except for these items which are discussed in Paragraphs 3.3.3.1 and 3.3.3.10, the body flap architecture is acceptable as designed for use on the operational Space Shuttle Orbiter.

3.3.4.2.8 Rudder/Speed Brake Hydraulic Actuation – Single failure point external leaks downstream of the switching valves in the existing rudder/speed brake hydraulic power drive unit can cause loss of all three hydraulic systems, which results in loss of the Orbiter.

The existing design of the rudder/speed brake hydraulic operating system (Figure 3-26) incorporates dual hydraulic switching valves. These valves automatically select one of the two remaining redundant hydraulic systems, one after another, after failure of the primary system. The selected system supplies power to both the rudder four-channel servo system and the speed brake four-channel servo system. The hydraulic portion of each channel of each servo system consists of three hydraulic components: (1) a servo valve, (2) a pressure transducer, and (3) a solenoid-operated bypass valve.

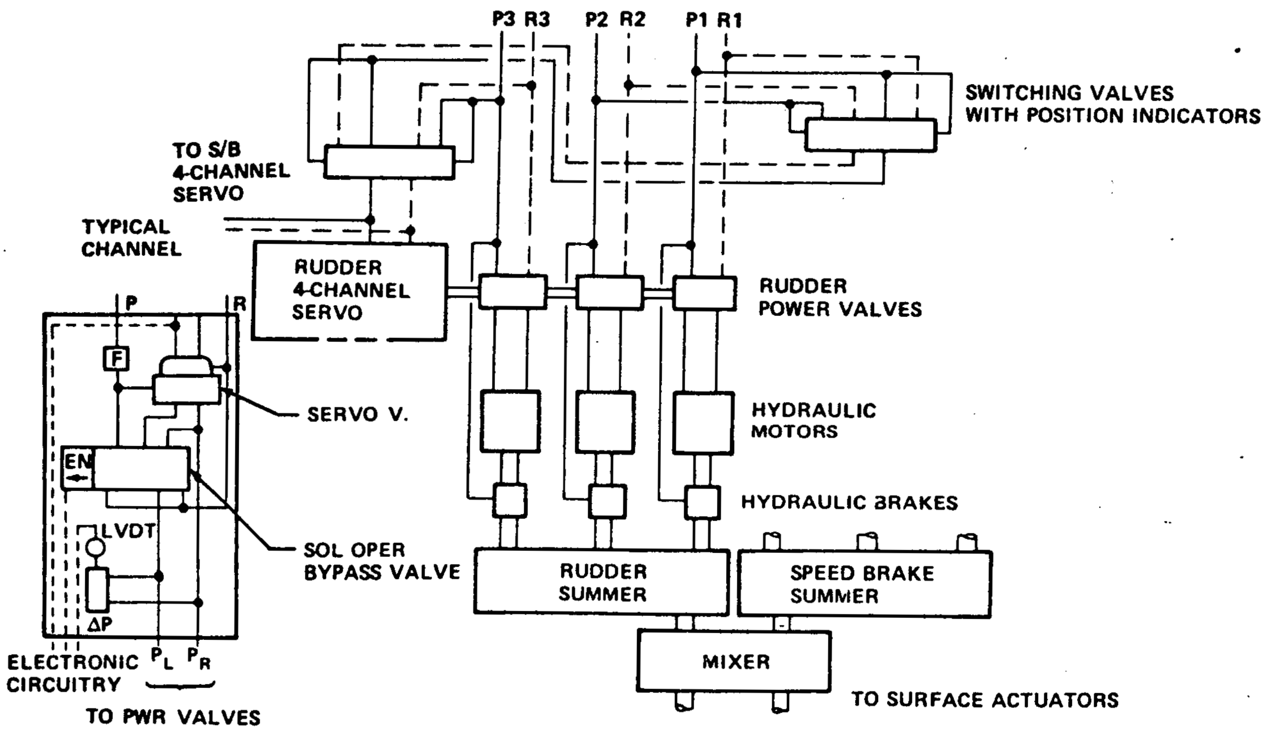

FIGURE 3-26 EXISTING RUDDER SPEED BRAKE DESIGN

If a single failure point external leak occurs downstream of the switching valves in any of the eight hydraulic servo channels (which contain 24 critical components), all three hydraulic systems may be lost, with subsequent loss of the Orbiter. Each critical component has numerous inherent single failure points which may result in failure of the hydraulic power drive unit as a pressure vessel. These points may be seal failures, fractured housings, or a bolt failure. The seal single failure points have been eliminated by incorporation of redundant seals or seal barriers except as noted in Paragraph 3.3.3. The problems of fractured housings and screw failures have not been adequately addressed. The R/SB PDU consists of individual components screwed together on a manifold that incorporates numerous drilled passages. Commercial aircraft service records show that similar component housings and manifolds have been subject to fracture failures and that screw failures have occurred as a result of overtorqued, undertorqued, or fractured screws. External leakage has also developed as a result of failure to lockwire and subsequent vibration which loosened the screws.

As an alternate design, Rockwell proposed a tandem rudder/speed brake hydraulic power drive unit (Figure 3-27) which eliminated all the single failure points as a pressure vessel in the four-channel servos. This design eliminated one switching valve but incorporated an additional four-channel servo system. The avionics impact was large because this approach doubled the wiring and the aerosurface servo amplifier (ASA) hardware for the rudder/speed brake actuation system. The quiescent flow was increased. The size, weight, and cost of the hydraulic PDU was increased.

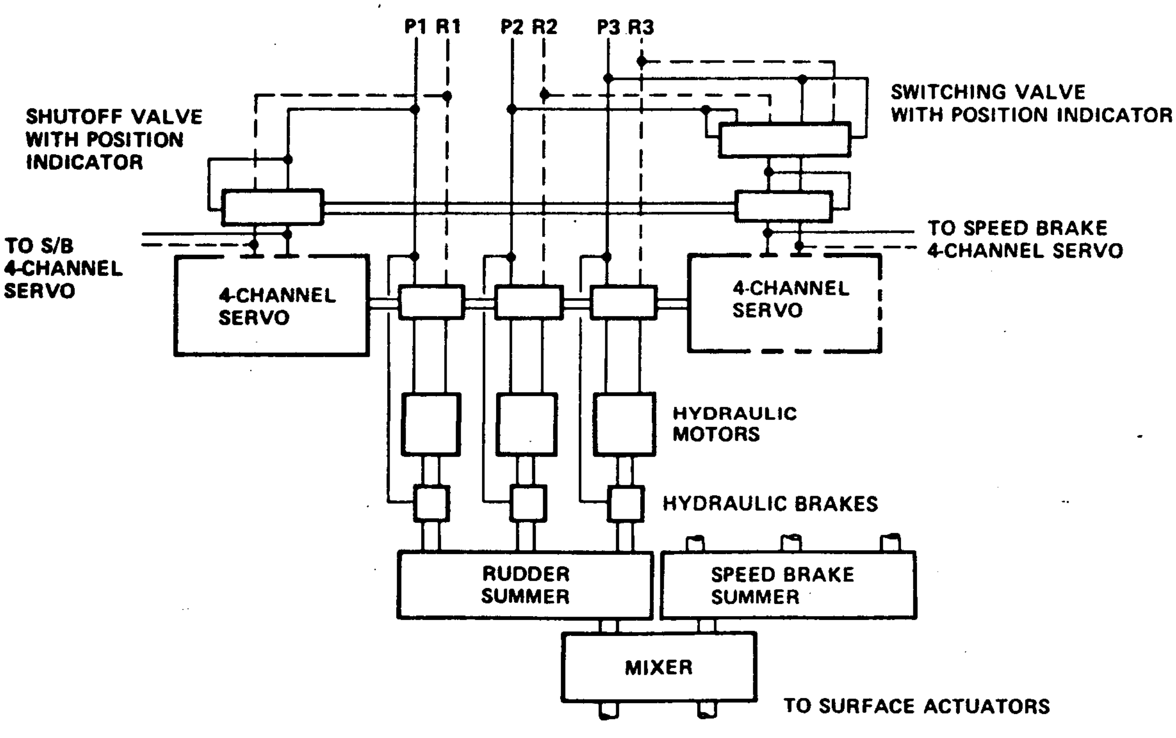

FIGURE 3-27. ROCKWELL PROPOSED SPEED BRAKE DESIGN

McDonnell Douglas Corporation proposes a design (Figure 3-28) that eliminates all the single failure points as a pressure vessel in the rudder/speed brake hydraulic power drive unit. The 24 components in the two four-channel servos will no longer be Criticality Category 1 items. This design eliminates the two existing large switching valves. The

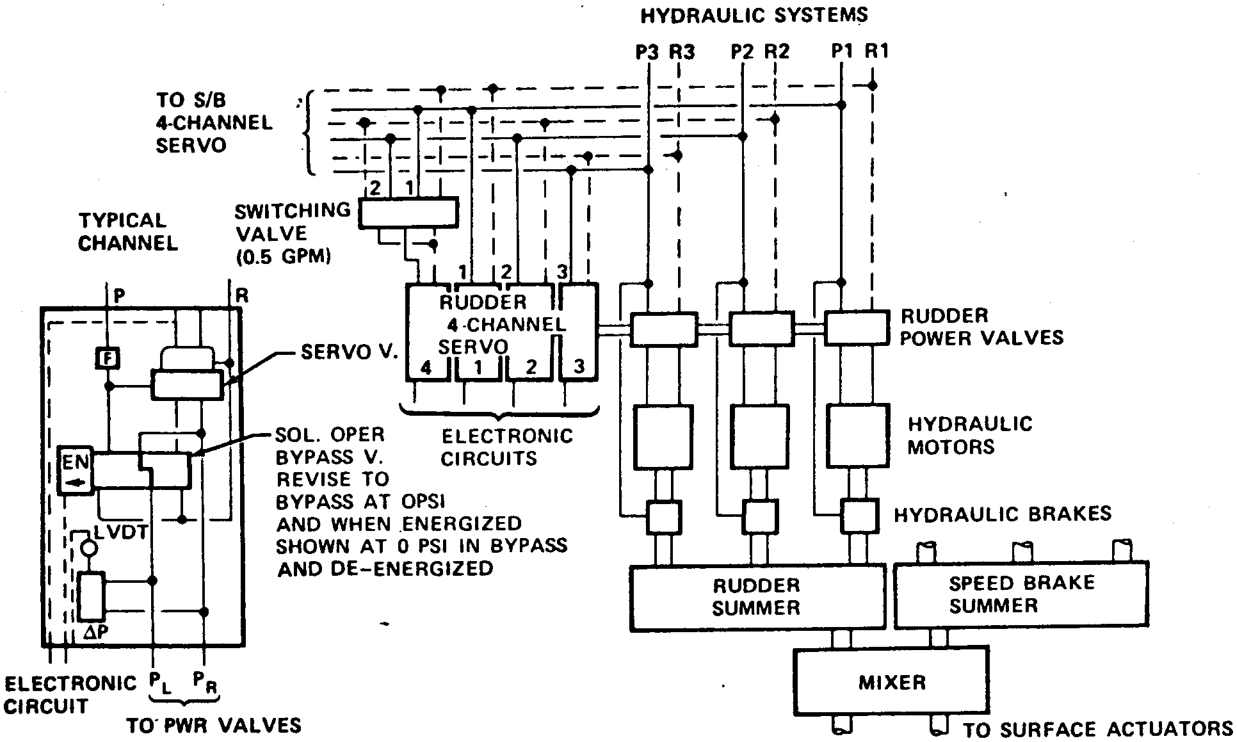

FIGURE 3-28. MCDONNELL DOUGLAS PROPOSED SPEED BRAKE DESIGN

hydraulic systems are rerouted in the hydraulic power drive unit so that a different hydraulic system supplies power to each channel of the rudder four-channel servo and the speed brake four-channel servo. Hydraulic System 1 supplies power to Channel 1; Hydraulic System 2 supplies power to Channel 2; and Hydraulic System 3 supplies power to Channel 3. A small 0.5-gpm switching valve is added to the power supply for Channel 4. Normally, Hydraulic System 1 supplies power to Channel 4, but if a failure of Hydraulic System 1 power occurs, Hydraulic System 2 supplies power to Channel 4. This switching valve is provided to preserve the existing fail operative/fail operative/fail safe design of the four-channel servos. With any one electrical failure, the servos will have three channels still operative for voting.

The pressure differences among the three hydraulic systems supplying the different channels is small except for transient pressures. The existing electronic circuitry is tolerant of these differences as it contains a time-delay provision.

The existing solenoid-operated bypass valves incorporated in each channel of the four-channel servo must be revised so that they bypass at 0 psi and when energized. Rip-stop construction must be incorporated to prevent crack propagation from causing loss of more than two hydraulic systems (and preferably only one) with any one failure.

With this proposed design, there is no change in the avionics, no change in the electronic circuitry, and no change in the ASA hardware. The resulting hydraulic power drive unit is smaller than the existing unit because two large switching valves are replaced by one small switching valve.

Incorporation of the proposed hydraulic power drive unit results in total weight savings of about 20 pounds. A rough-order-of-magnitude cost estimate based on a similar commercial aircraft change and updated to current prices is $2 million, including four ship sets and one for the FCHL. The impact on the schedule would be about 15 months.

It is also recommended that the rudder/speed brake gear ratio be reevaluated and, if it proves to be greater than required, it be revised to provide only the required design hinge moment. If the gear ratio can be reduced, the structural load requirements will be reduced and the hydraulic flow required for a given rudder rate will be reduced. This would result in an increased available rudder surface rate for combined flight control surface operation during both normal and single hydraulic system operation.

3.3.4.2.9 Elevon Actuation — The possible single failure points downstream of the switching valves in each elevon actuator package which can cause loss of all three hydraulic systems and result in loss of the Orbiter are too numerous to identify and avoid by overdesign and superior inspection procedures. There are four single type actuator packages, each of which drives one elevon surface. Each existing elevon actuator package (Figure 3-29) incorporates a four-channel servo which has 12 critical components, four dynamic feedback sensors, a switching valve manifold, a power valve manifold, and an actuator. This results in 19 critical components in each elevon actuator package, for a total of 76 critical components in the elevon actuation system, all of which

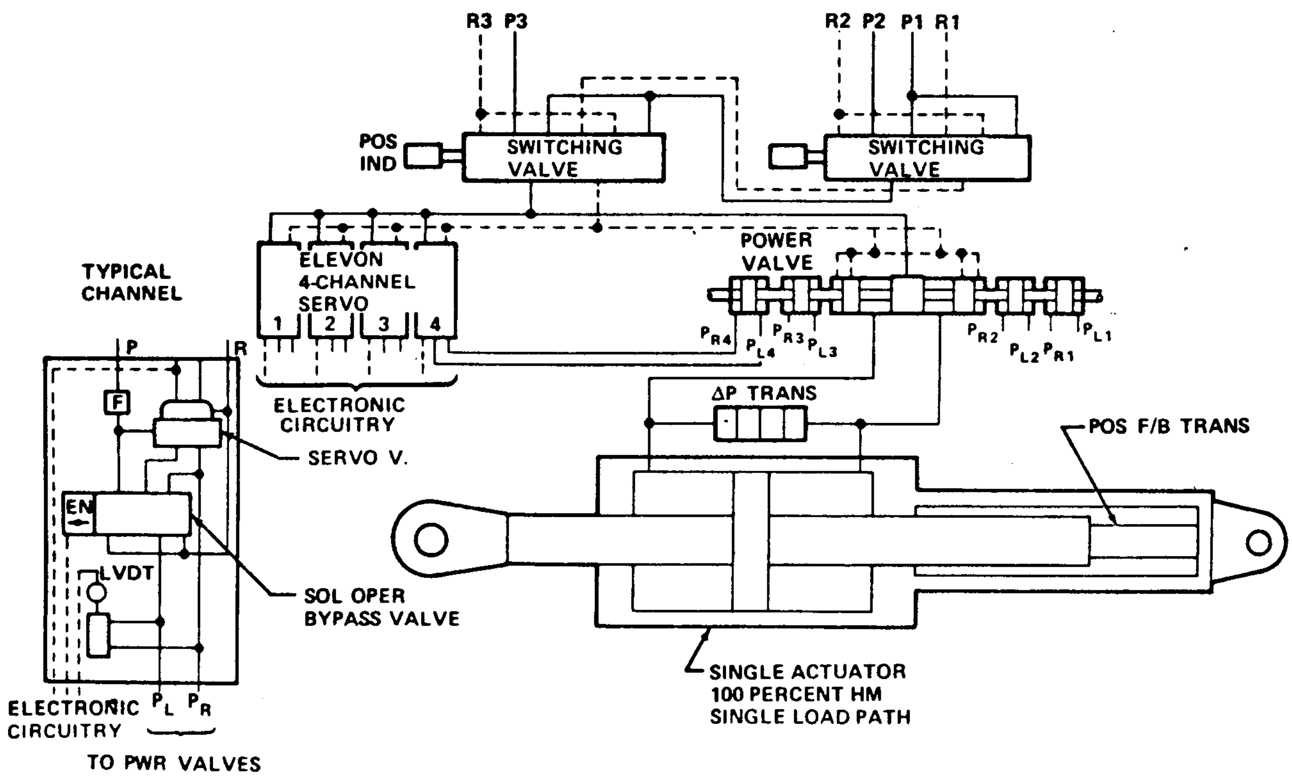

FIGURE 3-29. EXISTING DESIGN OF ELEVON ACTUATOR

have multiple inherent single failure points as a pressure vessel. If external leakage greater than 0.1 gpm develops in any of these 76 critical components, the three hydraulic systems may be lost, with subsequent loss of the Orbiter. The single failure points may be seal failures, fractured housings, or bolt failures. Seal single failure points have been adequately treated by incorporation of redundant seals and seal barriers. However, the problems of fractured housings and screw failures have not been properly addressed. Aircraft service records indicate that both of these problems exist on similar type actuator packages used on aircraft now in service. Since transport aircraft designs incorporate greater redundancy, such as redundant control surfaces as well as tandem actuators, the fractured housings and bolt failures that have occurred have not been catastrophic, but similar type failures on the Orbiter elevon actuator packages would be.

Each elevon actuator package incorporates two switching valves which automatically select one system after another after failure of the primary system for elevon power supply. This fact, in addition to the numerous single failure points which exist downstream of the switching valves, limits the redundancy and reliability that can be achieved with the existing Orbiter elevon actuation system.

All the elevon actuator packages must be operable to ensure safe flight and landing. Each is therefore a Criticality Category 1 hazard item in two ways: (1) it is a pressure vessel whose failure downstream of the switching valves will cause loss of all three hydraulic systems and subsequent loss of the Orbiter, and (2) it is a structural member the failure of which wil cause loss of control of that surface, and under adverse conditions, the subsequent loss of the Orbiter.

With the existing elevon actuation system and normal two or three hydraulic system operation, the flow available for combined flight control surface response during normal combined control demands is marginal during approach and landing under adverse conditions. This condition exists because the actuators are sized to deliver 100 percent design hinge moment. Different hydraulic systems supply each actuator to distribute the horsepower requirements among the systems and not overload any one system. However, this distribution increases the total flow requirement when roll control is superimposed on pitch control. There is a flow deficiency for single system operation during approach and landing and it is doubtful if a successful landing could be made with only one system operable. This situation will be explained and discussed in greater detail in the comparison of the recommended actuator design with the existing design.

An analysis based on commercial aircraft service records indicates the existing elevon actuation system is vulnerable to failure during its 10-year operational life. The average flight time for domestic aircraft is about the same as the Orbiter flight time; however, commercial aircraft do not have on-orbit time. Although the hydraulic systems are pressurized to only 60 psi and 300 psi during on-orbit time, this time will include 7 to 30 days of cyclic operation for thermal conditioning of the hydraulic fluid.

It must be recognized that there is little experience or data from which a failure rate probability can be established for the environments that will be encountered during on-orbit time. Nevertheless, on-orbit time becomes a factor in producing possible catastrophic failures with the existence of single failure points within a system.

Extrapolating from our DC-10 flight control actuator package service records (3,000,000 flight hours), there is a low probability of achieving no failures using the single actuator and switching valve concept presently baselined, even with a fortress type program incorporated. Therefore, it is recommended that tandem elevon actuator packages incorporating a fortress program consisting of rip-stop construction, fracture control plan or a dual load path, optimum design, and superior quality control methods be incorporated in the operational Space Shuttle Orbiter.

Rockwell proposed a tandem elevon actuator package design (Figure 3-30) that eliminated all the single failure points as a pressure vessel in the actuator packages. Although the material available does not specify rip-stop construction, it is assumed that the Rockwell design incorporated this feature as it is the only obvious method whereby all the single failure points could be eliminated in the proposed design.

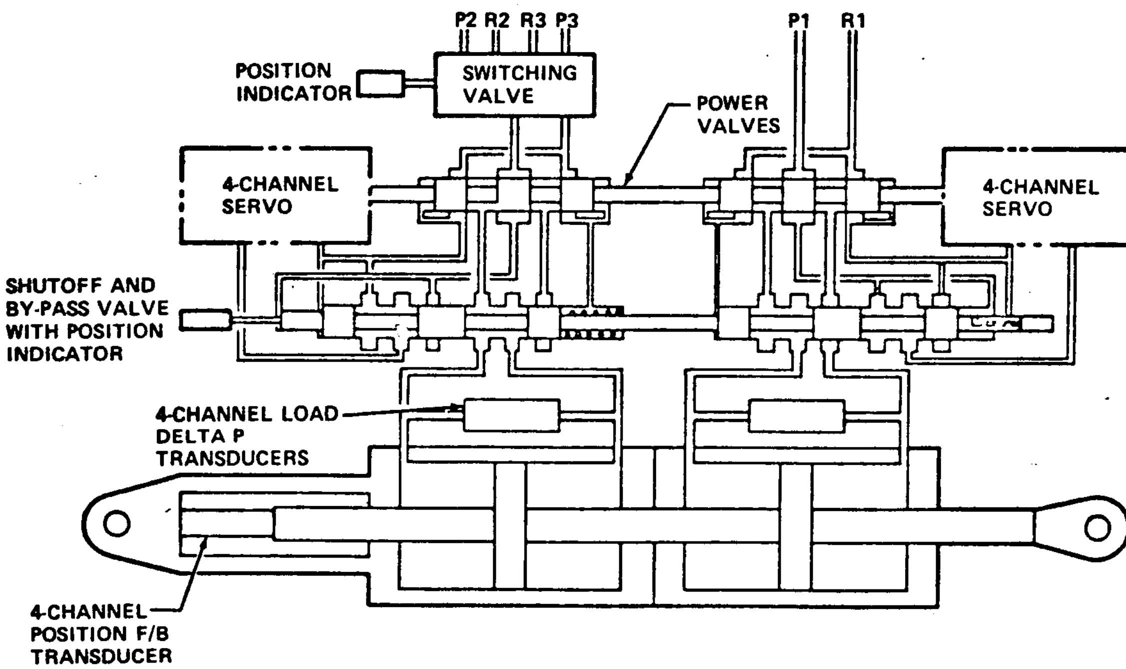

FIGURE 3-30. ROCKWELL PROPOSED TANDEM ELEVON ACTUATOR

Each half of the actuator produces 100 percent design hinge moment. Since the structure is designed for only 100 percent load, Rockwell added 2 linked shutoff and bypass valves with a position indicator that controls pressure supply to the tandem actuator so that only half the cylinder is operating at any time. This avoided the need for increasing the structural strength but decreases the reliability of the tandem actuator.

A four-channel servo was added for each elevon package, which has a large avionics impact. The electronic circuitry and ASA hardware were doubled for the elevon actuation system. There was a 7.5 percent increase in hydraulic power required. The actuator length increased and wing structure modifications and new actuator support fittings were required. The cost, weight, and schedule impact was large.

McDonnell Douglas Corporation (MDC) proposes tandem actuator packages (Figure 3-31) which eliminate all the single failure points as a pressure vessel in the elevon actuator packages. The 76 components will no longer be Criticality Category 1 items. The proposed actuator packages incorporate rip-stop construction to prevent fracture propagation that might cause the loss of more than two (preferably only one) hydraulic system. Additional soft seals can be avoided by using a special sandwich-type construction employing brazing.

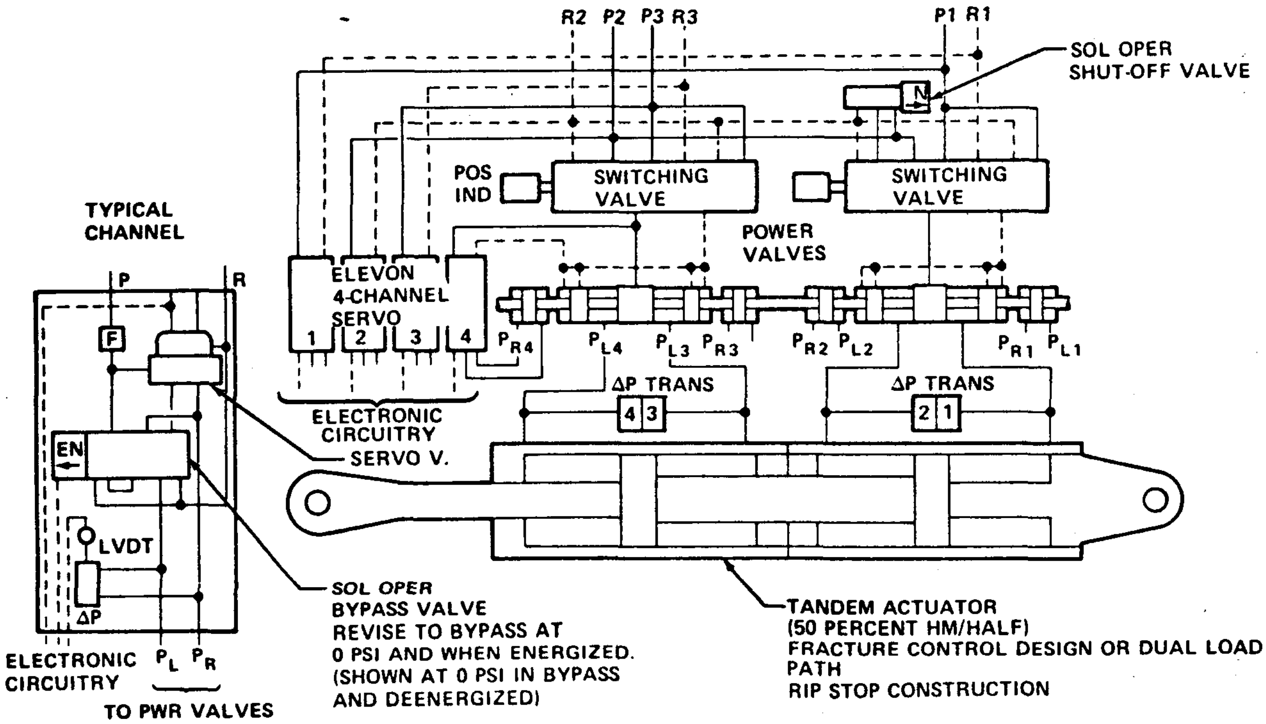

FIGURE 3-31. MCDONNELL DOUGLAS PROPOSED TANDEM ELEVON ACTUATOR

The hydraulic systems are rerouted in the actuator packages so that separate power is supplied to each channel of the four-channel servo. Hydraulic System 1 supplies power to Channel 1; Hydraulic System 2 supplies power to Channel 2; and Hydraulic System 3 supplies power to Channel 3. Channel 4 derives its power downstream of one of the switching valves so that Hydraulic System 3 is primary and Hydraulic System 2 serves as a standby source of power. This arrangement preserves the existing design criteria for the servo which is fail-operative/fail-operative/fail-safe; i.e., with any single electrical failure, three channels remain oprative for voting. This is the same approach used on the proposed rudder/speed brake hydraulic power drive unit redesign.

The pressure differences between the hydraulic systems supplying the channels are small except for transient pressures. The existing electronic circuitry is tolerant of these differences. The solenoid-operated bypass valve in each channel must be revised to bypass at 0 psi and when energized. This revision is minor.

Each half of the proposed tandem actuator produces approximately 50 percent design hinge moment. The normal actuator output is 100 percent design hinge moment with any two hydraulic systems operative, as both halves of the actuator normally are pressurized.

With this arrangement, improved surfaces rates are available for normal operation. The system supply can be such that additional flow is not required when roll control is superimposed on pitch control.

With the existing systems arrangement (Figure 3-32), Hydraulic System 2 is the primary supply for the left inboard elevon (LIE) and the right outboard elevon (ROE). For a 20 deg/sec pitch control command, 30.1 gpm is required for the LIE and 14.8 gpm for the ROE, for a total of 44.9 gpm. For a superimposed 20 deg/sec roll control command, a +30.1 gpm is required for the LIE and a −14.8 gpm for the ROE; i.e., it does not travel as far as it would have to for pitch control alone. Therefore, the total flow required for superimposed roll control command is 15.3 gpm. Thus, when added to the 44.9 gpm required for pitch control, it amounts to 60.2 gpm per system (Figure 3-32).

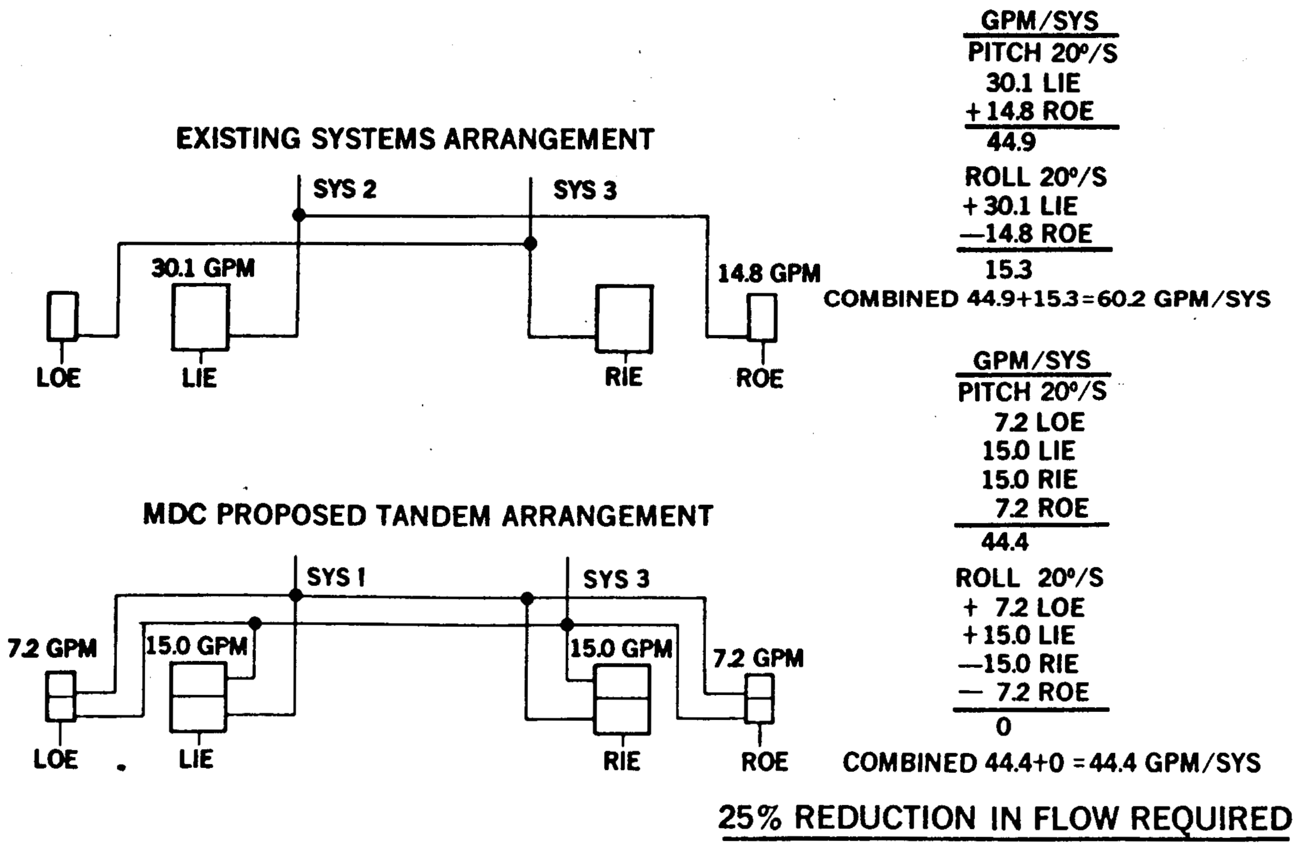

FIGURE 3-32. COMPARISON OF ELEVON SYSTEMS FLOW REQUIREMENTS

With system leakage and any required directional control, the pump capacity of approximately 68 gpm is exceeded. As the surface rates used in these calculations are normally of the same magnitude as those used in design, the existing systems are marginal in horsepower delivery, particularly during approach and landing under adverse conditions.

The same system is not primary on both inboard elevons in the existing design because then the pump flow delivery would be marginal for pitch control alone.

With the MDC-proposed tandem elevon actuator packages (Figure 3-32), System 1 can be made primary on half the tandem on all elevon actuator packages and System 3 can be made primary for the other half without exceeding pump flow delivery. This results from the fact that each half of the tandem produces only about 50 percent hinge moment and therefore needs only half the flow required by the single actuator to produce the same elevon surface rate.

For a 20 deg/sec pitch control command, a total of 44.4 gpm is required (7.2 gpm LOE, 15.0 gpm LIE, 15.0 gpm RIE, and 7.2 gpm ROE). A slight reduction in flow was obtained by rerouting separate systems to each channel of the four-channel serevo, and that is the reason flow requirements are slightly less than half of those required by the existing single actuators.

Now, when a roll command of 20 deg/sec is superimposed on pitch command, an additional 7.2 gpm and 15.0 gpm are required for the left elevons, but the right elevons do not have to move as far as they would have for pitch command alone, and a negative requirement of 15.0 gpm and 7.2 gpm results. Therefore, no additional flow is required for roll command superimposed on pitch command with the proposed arrangement.

The total flow required is 44.4 gpm per system as compared with 60.2 gpm per system with the existing arrangement. This is a 25 percent reduction in the required flow for combined surface commands. More importantly, the 44.4 gpm per system required by the proposed tandem actuator packages, when combined with system leakage and directional control requirements, does not exceed the existing pump delivery capacity. In addition, surface rates only slightly subnormal are obtained for single system operation during approach and landing.

If either System 1 or 3 is the only remaining operative system, automatically only half the tandem actuators are operative. For the case of System 2 being the only operative system, a small solenoid-operated shutoff valve is installed in each actuator package. Immediately before approach and landing, these valves are shut off, which inactivates half of each tandem actuator package. Therefore, when only one system is operative, the same flow is required for surface response as for normal operation. However, the hinge moment is only about 50 percent of that which is normally available. Since q is reduced at the slower speeds encountered during approach and landing, the loads are reduced. The hinge moment available with only half the tandem actuator operative is adequate for landing.

A comparison of surface rate capabilities (Figure 3-33) shows that with one hydraulic system operating, the surface rates available with the proposed system are increased more than 100 percent over those available with the baseline system. With two hydraulic systems operating the surface rates available with the proposed system are increased appreciably over those available with the baseline system, particularly for combined surface commands.

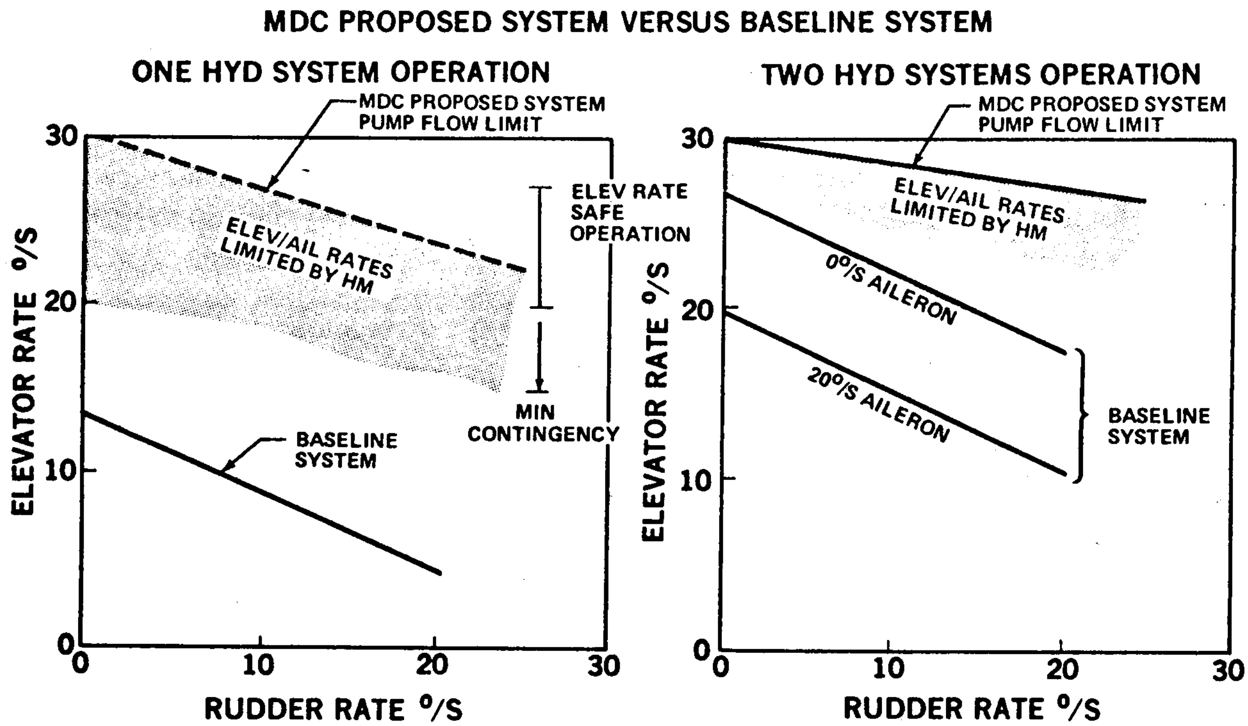

FIGURE 3-33. SURFACE RATE CAPABILITIES

The MDC-proposed elevon tandem actuator packages (Figure 3-34) can be fit into the same envelopes as the existing single actuator packages. The same pin center lengths have been retained by use of an internal tail rod. The identical normal operating loads have been produced by balancing the actuator areas. The actuator is made smaller in diameter so that only 50 percent design hinge moment is produced by each half. Thus, the existing wing structure and support fittings can be used without change. The four-channel servo has been retained so that no change is required in the electronic circuitry or ASA hardware.

The proposed tandem actuator package retains two switching valves and a control valve. Another control valve and a small solenoid-operated shutoff valve have been added. It is recommended that a combination of a fracture control plan for part of the actuator and a dual load path for the remainder be incorporated.

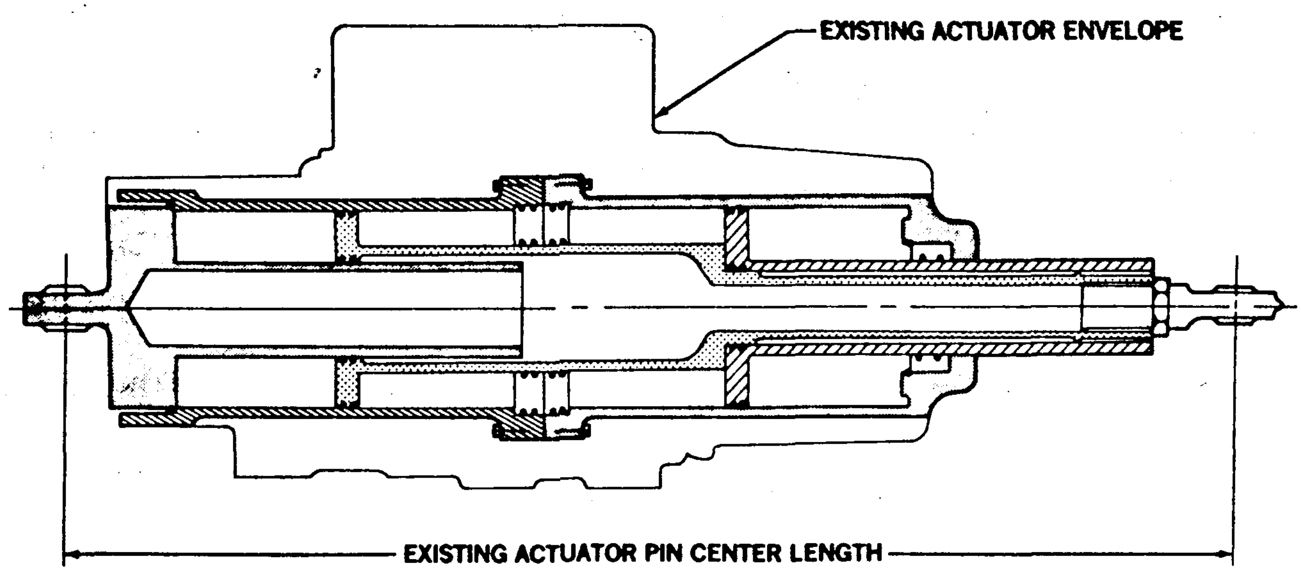

FIGURE 3-34. MCDONNELL DOUGLAS PROPOSED TANDEM ELEVON ACTUATOR

The weight change with incorporation of the proposed tandem elevon actuator packages is estimated to be less than 100 pounds total for the Orbiter. Some of this weight may be saved by incorporating a fuel management system, since Systems 1 and 3 become primary and System 2 becomes a standby system with the proposed arrangement. Therefore, the hydrazine fuel carried to power hydraulic System 2 could be reduced, and transfer valves used to transfer fuel from System 1 and System 3 if a failure in either of those systems occurs.

The cost of implementing the change in the tandem actuators should be about equivalent to that which was incurred in changing from Hydraulic Research elevon hardware to Moog hardware. A rough-order-of-magnitude cost based on a similar change made on a commercial aircraft and updated to current prices is $5 million, which includes four shipsets of hardware, one set for the flight control hydraulic laboratory and hardware for qualification testing. The schedule impact is about 15 months.

The total weight increase is 80 pounds for incorporating the MDC revisions on the rudder/speed brake hydraulic power drive unit and the tandem elevon actuator packages as compared with the total weight increase of 985 pounds for incorporating Rockwell's proposed revisions. The weight increase of Rockwell's revisions was greater because of an increase in weight in the wing structure and avionics required by its proposal, whereas there are no changes in these areas required for our proposal. In addition, both of Rockwell's proposed actuating packages weigh more than our actuating packages because they are larger and more complex.

A functional comparison of the existing single elevon actuator packages with the MDC-proposed tandem elevon actuator packages is presented in Figure 3-35.

	EXISTING SINGLE ACTUATOR PACKAGE	MDC PROPOSED TANDEM ACTUATOR PACKAGE
• RIP STOP CONSTRUCTION	NO	YES
• SINGLE FAILURES DOWNSTREAM OF SWITCHING VALVES	LOSE ORBITER LOSE 3 HYDRAULIC SYSTEMS.	1/2 HINGE MOMENT AVAILABLE NORMAL LANDING (WILL NOT LOSE BOTH SYSTEMS 1 AND 3 WITH ANY SINGLE FAILURE)
• SINGLE HYDRAULIC FAILURE IN 4 CHANNEL SERVO	LOSE ORBITER LOSE 3 HYDRAULIC SYSTEMS.	FAIL OPERATIONAL NORMAL LANDING
• ALL SYSTEM OPERATIVE	COMBINED COMMANDED SURFACE RATES MARGINAL, THEREFORE PRIORITY RATE LIMITING WAS USED. (NOT SUCCESSFUL ON ALT 101).	COMBINED COMMANDED SURFACE RATES AVAILABLE WITHOUT PRIORITY RATE LIMITING
• FAIL ONE SYSTEM UPSTREAM OF SWITCHING VALVES	FAIL OPERATIONAL	FAIL OPERATIONAL
• FAIL SYSTEMS 1 AND 3 UPSTREAM OF SWITCHING VALVES	MAY LOSE ORBITER, SINGLE SYSTEM FLOW AND SURFACE RATE DEFICIENT AT LANDING	FAIL OPERATIONAL NORMAL LANDING
• FAIL SYSTEMS 1 AND 2 UPSTREAM OF SWITCHING VALVES	MAY LOSE ORBITER, SINGLE SYSTEM FLOW AND SURFACE RATE DEFICIENT AT LANDING	1/2 HINGE MOMENT AVAILABLE NORMAL LANDING
• FAIL SYSTEMS 2 AND 3 UPSTREAM OF SWITCHING VALVES	MAY LOSE ORBITER, SINGLE SYSTEM FLOW AND SURFACE RATE DEFICIENT AT LANDING	1/2 HINGE MOMENT AVAILABLE NORMAL LANDING

FIGURE 3-35. FUNCTIONAL COMPARISON OF ELEVON ACTUATORS

3.3.4.2.10 Comments on Space Shuttle Hydraulic Servocontrol Actuator Single-Load-Path, Single-Cylinder Arrangements – MDC has accumulated 3 million hours of flight time reliability data on DC-10 servocontrol packages which approximate those used in the Space Shuttle. These data were reviewed and the failures analyzed and then applied to the Space Shuttle hardware to arrive at some probability of failures for various actuator arrangements. The results are given in Table 3-2 and graphically presented in Figure 3-36. The effects of extended periods of time in space have not been included; thus, the results give but gross relative comparisons. The results do show the distinct advantage of the dual-load-path arrangment when compared to the single- load-path design. All flight control and TVC actuators on the Space Shuttle are single-load-path, single-cylinder arrangements.

Arrangement No. 12 is for the Orbiter elevon actuator as it is presently configured. Applying a fracture control plan to the hardware removes five of the original 24 critical failure paths used to develop the probability of failure of 5.1×10^{-6} obtained by applying Douglas Aircraft flight reliability data. Thus, arrangement No. 11 with a probability of failure of 4×10^{-6} for 19 critical failure paths was not greatly improved. By repiping the servocontrol channels to eliminate the loss of all hydraulic supplies in the event of a fractured housing in any one of the servo channels reduces the probability of failure rate to 1.7×10^{-6} (arrangement No. 8). Because the actuator is assembled with the use of many screws, numerous chances of a failure still exist. A large improvement is apparent with the use of a single-load-path tandem actuator (arrangement No. 6).

TABLE 3-2

PROBABILITY OF FAILURE FOR VARIOUS HYDRAULIC SERVO ACTUATOR ARRANGEMENTS

	SERVO CONTROL SYSTEM	ARRANGE-MENT NUMBER	PROBABILITY OF FAILURE *	SERVO CHANNEL HYD PIPING	NUMBER OF ACTUATORS OR LOAD PATHS		THREE HYDRAULIC SYSTEMS			VERFICATION	
					1	2	SINGLE ACTUATOR	TANDEM ACTUATOR	REMAINING REDUNDANT SYSTEMS	CONVENTIONAL ENDURANCE TESTING	FRACTURE CONTROL PLAN
	ELEVON	1	2.4×10^{-11}	I		√		√	1		√
	ELEVON	2	2.4×10^{-11}	I		√	√		1		√
	ELEVON	3	2.5×10^{-11}	I		√		√	1	√	
	ELEVON	4	2.6×10^{-11}	I		√	√		1	√	
***	ELEVON	5	1.0×10^{-9}	I	III			√	1		√
	ELEVON	6	2.1×10^{-7}	I	√			√	1		√
	ELEVON	7	4.2×10^{-7}	I	√			√	1	√	
	ELEVON	8	1.7×10^{-6}	I	√		√		2		√
	ELEVON	9	2.3×10^{-6}	I	√		√		2	√	
	ELEVON	10	2.5×10^{-6}	I	√		√		1	√	
	ELEVON	11	4.0×10^{-6}	II	√		√		2		√
**	ELEVON	12	5.1×10^{-6}	II	√		√		2	√	
***	SSME -TVC	13	3.5×10^{-8}	II	√		√		1		√
**	SSME -TVC	14	1.7×10^{-7}	II	√		√		1	√	
***	R/SB	15	1.2×10^{-12}	I	–	–	–	–	1		√
**	R/SB	16	1.1×10^{-6}	II	–	–	–	–	1	√	
***	SRB -TVC	17	5.6×10^{-9}	II	√		√		1		√
**	SRB -TVC	18	1.7×10^{-8}	II	√		√		1	√	

I INDIVIDUAL HYDRAULIC SYSTEM POWERING EACH SERVO CHANNEL

II ONE HYDRAULIC SYSTEM POWERING ALL SERVO CHANNELS

III PARTS OF LOAD PATH ARE REDUNDANT

* THESE VALUES ARE APPROXIMATIONS BASED ON DOUGLAS DC-10 AIRCRAFT SERVICE DATA COVERING 3,000,000 FLIGHT HOURS.

** EXISTING CONFIGURATION

*** RECOMMENDED CONFIGURATION

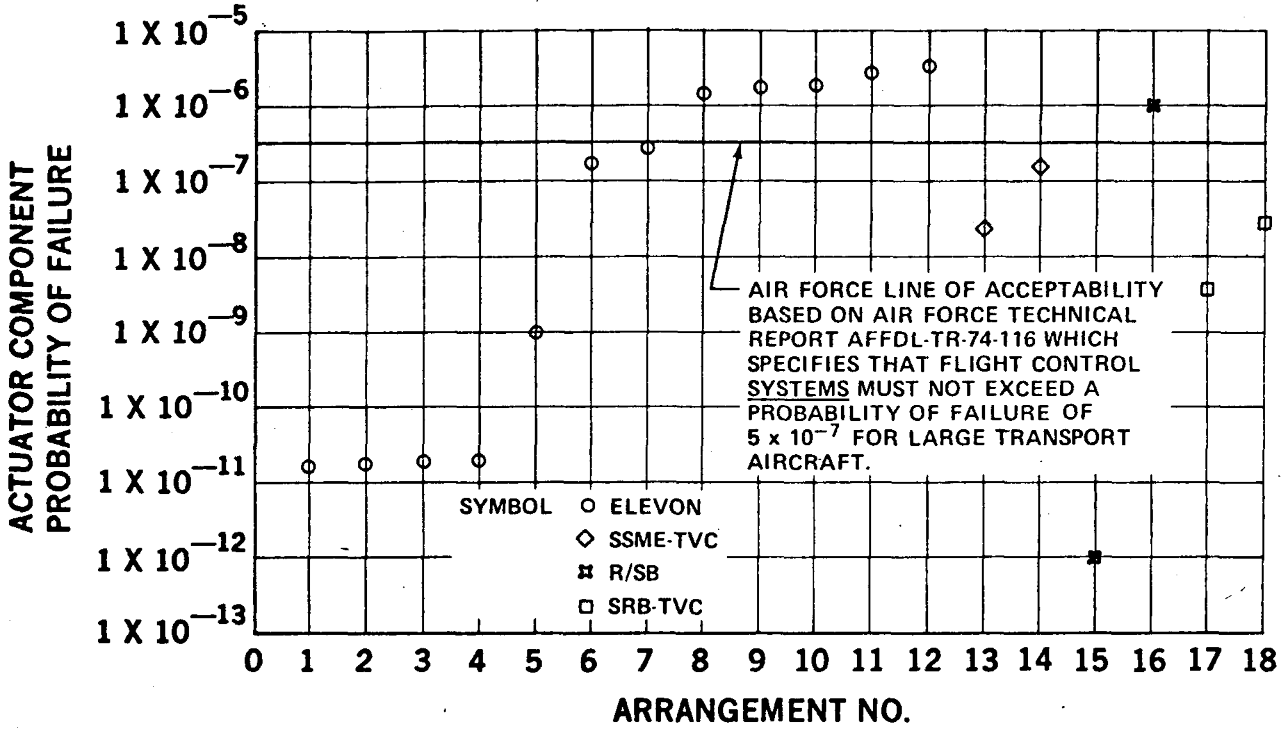

FIGURE 3-36. PROBABILITY COMPARISON FOR VARIOUS ACTUATOR ARRANGEMENTS

The actuator reliability is greatly improved when the loadpath as well as the cylinder becomes dual, as shown in arrangement No. 3. Commercial flight control hydraulic servoactuators in most cases comply with arrangement No. 3 or 4. They use redundant control surfaces which are driven by a tandem-cylinder, single-loadpath actuator driving each individual surface. The MDC-proposed tandem actuator (arrangement No. 5) has a dual loadpath through portions of its design. A dual loadpath throughout could also be provided, but at the expense of additional weight. Its probability of failure would then be the same as arrangement No. 3.

The SSME-TVC and SRB-TVC actuators (arrangements 14 and 18, respectively) without the fracture control plan applied show a lower probability of failure than the elevon actuator. This is due to the fact that they are in operation a shorter period of time, and a larger leakage rate can be accommodated by this hardware. For these reasons, applying a fracture control plan to the hardware shows a greater improvement.

The rudder/speed brake hydraulic module (arrangement No. 16) as it now exists has a lower probability of failure than the elevon actuator even though they operate over the same time interval. This is because some of the failure modes associated with the actuator, such as a single cylinder and loadpath, are not found in the rudder/speed brake. Incorporating the changes in the rudder/speed brake design as recommended by MDC will provide the redundancy required to greatly decrease its probability of failure (arrangement No. 15).

The Air Force line of acceptability (Figure 3-36) is based on the analysis of *complete* flight control systems. The rest of the points in the figure are for individual modules. The probability of failure of the modules must be considerably below the Air Force line of acceptability to allow a system to be acceptable.

These data are presented to show relative merits between modules of various configurations and to help one judge the advantages of one arrangement over another.

3.3.4.2.11 Orbiter Architecture Assessment Summary – It is recommended that a Fortress program be implemented for the SSME TVC actuator packages, that the MDC-proposed redesign of the rudder/speed brake hydraulic power drive unit and the MDC-proposed tandem elevon actuator packages be incorporated in the Space Shuttle Orbiter as soon as possible.

These recommended revisions will result in eliminating 100 components from being Criticality Category 1 items and will increase the combined control surface rates that are available during the critical approach and landing phase of flight to make them conform with normal design practice.

3.3.4.3 Calculations – The following calculations are used to analyze the Space Shuttle hydraulic system architecture.

3.3.4.3.1 SRB Horsepower Requirements (Normal Operation) – The SRB TVC hydraulic actuator systems are designed to deliver sufficient horsepower to produce a minimum gimbal rate of 5 deg/sec under rated load. With loss of one hydraulic system, the remaining system increases its horsepower delivery. Assuming the actuator cylinder and rod diameters have been correctly chosen, the actuator flow required to produce a 5-deg/sec gimbal rate is calculated as follows:

$$A = A_C - A_R$$

where

$$\text{Actual Cylinder Diameter, } D_C = 7.312^{+0.001}_{-0.000}\text{, Area, } A_C = 41.991 \text{ in.}^2$$

$$\text{Rod Diameter, } D_R = 3.497^{+0.000}_{-0.001}\text{, Area, } A_R = 9.605 \text{ in.}^2$$

$$\text{Net Cylinder Area, } A = 32.386 \text{ in.}^2$$

Piston travel rate, $\dot{x}_p = 6.34$ ips for 5 degrees per second gimbal rate.

The cylinder rated flow, Q_c is

$$Q_c = \dot{x}_p x A$$

$$Q_c = 6.34 \times 32.386 = 205.333 \text{ cis} = 53.333 \text{ gpm}$$

The actuator package specified maximum leakage $Q_L = 3$ gpm.

Then the actuator rated flow, Q_A is

$$Q_A = Q_c + Q_L = 53.333 + 3 = 56.333 \text{ gpm}$$

At rated flow, Q_A, the pressure drop, ΔP_N, through the piping network (filter, fittings, hoses, and manifold) is 34 psi at 120°F. Reservoir pressure P_R is 60 psi.

In order to achieve the desired rate of 5 degrees per second, i.e., an actuator stroke of 6.34 ips, under rated load, the pressure drop through the actuator package ΔP_{AA} at rated flow with the control valve wide open must not exceed the value calculated below.

The pressure required for rated load (ΔP_{RL}) is

$$\Delta P_{RL} = \frac{M}{LxA} = \frac{4.2 \times 10^6}{66.33 \times 32.38} = 1956 \text{ psi}$$

The allowable pressure drop through the actuator package at rated flow (ΔP_{AA}) is

$$\Delta P_{AA} \leqslant P_S - [P_{RL} + P_N + P_R]$$

$$\Delta P_{AA} \leqslant 3000 - [1956 + 34 + 60] = 960 \text{ psi}$$

where:

ΔP_{RL} = Pressure required for rated load (psi)

M = Rated torque load = 4.2×10^6 in. lb

L = Moment arm = 66.3 in.

A = Cylinder net area = 32.386 in.^{2}

P_{AA} = Allowable pressure drop through actuator package at rated flow (psi)

ΔP_N = Pressure drop through flow network at rated flow = 34 psi

P_R = Reservoir pressure = 60 psi

P_S = System pressure = 3000 psi

With 3000 psi inlet pressure to the actuator package, a load equivalent to 1960 psi in the actuator, and the control valve fully open, the piston rod travels at 8.5 in./sec. This information was verified by test at Moog and verbally confirmed by Moog.

The test flow (Q_T) was

$$Q_T = \frac{(\dot{x}_T)(A)(B)}{C}$$

$$Q_T = \frac{(8.5)(32.38)(60)}{231} = 71.488 \text{ gpm}$$

The pressure drop through the actuator at the test flow (ΔP_T) was

$$\Delta P_T = P_I - \Delta P_{RL} = 3000 - 1960$$

$$\Delta P_T = 1040 \text{ psi}$$

where:

Q_T = Test flow (gpm)

$\dot{x}_T$ = Test piston travel rate = 8.5 in./sec

A = Cylinder net area = 32.386 in.^{2}

B = 60 sec/minute

C = 231 in.^{3}/gallon

ΔP_T = Pressure drop through actuator at test flow, psi

P_I = Actuator inlet pressure = 3000 psi

At rated flow the pressure drop across the actuator package with the control valve fully open using the above test data (ΔP_A) is

$$\Delta P_A = \frac{Q_A{}^2 \times P_T}{Q_T{}^2} = \frac{(56.333)^2 \times (1040)}{(71.488)^2}$$

$$\Delta P_A = 645.79 \text{ psi}$$

where

ΔP_A = Calculated pressure drop through the actuator package using above test data (psi)

The pressure drop through the actuator package is within the desired limit, ≤960 psi, as calculated in the preceding equation. Therefore, a gimbal rate of 5 deg/sec is available. In fact, it will exceed 5 deg/sec if not limited by the software.

3.3.4.3.2 SRB Standby Power (113 Percent Overspeed) – With the failure of one hydraulic system, a gimbal rate of 3 deg/sec under rated load is specified. Therefore, the hydraulic pump must deliver sufficient flow for operation of the two actuators as follows:

$$\text{Flow Required} = 2\left[\frac{Q_c \times 3}{5} + Q_L\right]$$

$$= 2\left[\frac{53.33 \times 3}{5} + 3\right] = 70 \text{ gpm}$$

where

Q_c = Cylinder rated flow, gpm

Q_L = Actuator package leakage, gpm

With the APU operating at 113 percent times rated speed minus 8 percent of 100 percent, which corresponds to pump operation at 113 percent rated speed minus 8 percent of 100 percent rated speed, the pump delivers

$$Q_{P_{MIN}} = \frac{[(1.13)(P_{RS}) - (0.08)(P_{RS})]\ (P_D \times P_{VE})}{231}$$

$$= \frac{[(1.13)(3804) - (0.08)(3804)]\ (4.3 \times 0.9363)}{231}$$

$$= \frac{(3994)(4.3)(0.9363)}{231}$$

$$= 69.62 \text{ gpm}$$

where

P_{RS} = Pump rated speed (100 percent), rpm

P_D = Pump displacement/rev (cu in.)

P_{VE} = Pump volumetric efficiency, percent (pump specification requires 66.3 gpm delivery at 3804 rpm, which is 93.63 percent)

The gimbal rate under the above conditions is

$$\text{Gimbal rate} = 5\left[\frac{\frac{Q_{P_{MIN}}}{2} - 3}{Q_c}\right]$$

$$= 5\left[\frac{\frac{69.62}{2} - 3}{52.33}\right]$$

$$= 2.98 \text{ deg/sec}$$

where:

$Q_{P_{MIN}}$ = Minimum pump delivery (gpm)

Q_c = Cylinder rated flow (gpm)

The gimbal rate is marginal under adverse conditions, but essentially satisfies the 3 deg/sec requirement. This calculation has assumed that an overspeed of 113 percent, identical to the Orbiter overspeed, is incorporated in the SRB.

3.3.4.3.3 SRB Standby Power (No Overspeed) – If the horsepower delivery problem were approached as for an aircraft application, every effort would be made to design the systems so that with the loss of one hydraulic system, the remaining system would not be required to increase its horsepower delivery, and would thereby eliminate the need for an APU overspeed operation.

When standby power is required, the single hydraulic pump in the remaining operative system at its normal flow delivery (103 percent rpm normal Orbiter hydraulic pump output) provides the specified 3 deg/sec gimbal rate emergency operation requirement without requiring APU overspeed operation.

The nominal gimbal rate (GR_{NOM}) is calculated as follows:

$$GR_{NOM} = 5\left[\frac{\frac{(P_N)(P_D)(P_{VE})}{2C} - Q_N}{Q_c}\right]$$

$$GR_{NOM} = 5\left[\frac{\frac{(3918)(4.3)(0.9363)}{2\,(231)} - 2.3}{53.33}\right]$$

GR_{NOM} = 2.99 deg/sec

where

GR_{NOM} = Nominal gimbal rate, deg/sec

P_N = Nominal pump speed, 103 percent rated rpm

P_D = Pump displacement/rev, cu in./rev

P_{VE} = Pump volumetric efficiency, percent (see Paragraph 3.3.4.3.2)

Q_N = Nominal actuator package leakage, gpm

C = 231 cu in./gallon

Q_c = Cylinder rated flow (gpm) (see Paragraph 3.3.4.3.1)

With the loss of one hydraulic system and an accumulation of adverse tolerances in the remaining operative hydraulic system, the available maximum gimbal rate is 2.67 deg/sec, as calculated below.

$$GR_{ADV} = 5\left[\frac{\dfrac{(P_N - 0.08\,P_{RS})(P_D)(P_{VE})}{2C} - Q_L}{Q_c}\right]$$

$$GR_{ADV} = 5\left[\frac{\dfrac{(3918 - 304)(4.3)(0.9363)}{(2)(231)} - 3}{53.33}\right]$$

GR_{ADV} = 2.67 deg/sec

where:

GR_{ADV} = Gimbal rate with adverse tolerances, deg/sec

P_N = Nominal pump speed (103 percent rated), rpm

P_{RS} = Pump rated speed (100 percent) rpm

P_D = Pump displacement/revolution, cu in./rev

P_{VE} = Pump volumetric efficiency, percent

Q_L^* = Actuator package maximum leakage (gpm)

C = 231 cu in./gallon

Q_c = Cylinder rated flow (gpm) (see Paragraph 3.3.4.3.1)

3.4 CONCLUSIONS AND CORRECTIVE CONCEPTS

A product of this assessment is a listing of the single failure points described for NASA in our final presentation and material (see the Summary section of Appendix B). In addition, each section of this report expands on the background data describing each single failure point. Where possible, recommended changes are provided. In some cases, corrective action has already been initiated (see Table 3-3).

TABLE 3-3

SFP ITEMS IDENTIFIED

	Total	Closed*	Open
Booster	234	180	64
Orbiter	471	316	225
Total	705	496	289

*Closed – Additional Tests Indicated OK
– Corrective Action Taken

Summary and recommendations sections for both the Solid Rocket Booster and the Orbiter hydraulic systems are contained in the Systems Architecture Assessment portion of this report.

It is recognized that some of the hydraulic equipment was designed to satisfy flight performance requirements stated in specification control documents. This assessment team has taken exception to some of these requirements as being insufficiently definitive; e.g., "SSME TVC subsystem ascent mode. Safe abort capability shall be provided with the loss of one hydraulic subsystem." No reference is made to a single failure point in the servo actuator which can lose two hydraulic systems at the SSME TVC. This condition could result in questionable abort and landing capability.

In addition to having numerous single failure points, the elevon system appears to provide inadequate control surface rates during approach and landing. This condition exists with all three systems operative and becomes worse with two systems inoperative. An alternative configuration for the elevon actuation system has been proposed which can eliminate these deficiencies.

Appendix A provides a summary listing of problems discussed in the text of this report. It is the list provided with the final presentation at NASA-Headquarters at Washington, D.C., updated to include a few items which were omitted at that time.

APPENDIX A

SUMMARY LIST OF PROBLEMS

NOTE: ITEMS ADDED OR REVISED SINCE FINAL PRESENTATION ON JULY 11, 1978 ARE PRECEDED BY AN ASTERISK*.

SFP SUMMARY
BOOSTER

NO.	ITEM	STATUS	QTY OF SFP'S	REMARKS	RESPONSE	EFFECTIVITY
1.0	SRB COMPONENTS					
1.1 •	SRB RESERVOIR OVERFILLING – RELIEF VALVE CAPPED	OPEN	SFC-4	LAUNCH HOLD WARNING FOR OVERFILL, UNCAP RELIEF VALVE		
*1.2	SRB SERVICE DISCONNECT PANEL	OPEN	SFC-8	PROVIDE LOCK TO KEEP SHUTOFF VALVE FROM ROTATING IN PANEL		
1.3	PIPING AND HOSE FAILURE FROM PUMP RIPPLE AND SURGES	OPEN	SFC-4	PERFORM PUMP RIPPLE TESTS		
1.4	SWITCHING VALVE JAMMED – TVC	OPEN	4	ADD INLET SCREENS TO REDUCE CHANCE FOR JAMMING		
1.5	POWER VALVE JAMMED – TVC	OPEN	4	ADD INLET SCREENS TO REDUCE CHANCE FOR JAMMING		
1.6	LOCK VALVE JAMMED – TVC	OPEN	4	ADD INLET SCREENS TO REDUCE CHANCE FOR JAMMING		
*1.7	TVC ACTUATOR PISTON SEAL FAILURE	OPEN	4	ADD BARRIER SEAL		
*1.8	FAILURE OF TVC SWITCHING VALVE TO FUNCTION PROPERLY			NOTE: THIS RESULTS IN A CRIT 1U CONDITION WHEN COMBINED WITH LOSS OF A HYDRAULIC SYSTEM. ADD CHECK VALVES AT INLET OR PROVIDE BARRIER SEAL		
	SEAL NO. 2	OPEN	4			
	SEAL NO. 3	OPEN	4			
1.9	LOSS OF TVC ACTUATOR PACKING GLAND	OPEN	8	PROVIDE POSITIVE LOCK		
*1.10	TVC ACTUATOR NEEDS FRACTURE CONTROL VERIFICATION	OPEN	18	IMPLEMENT AS SOON AS POSSIBLE		
*1.11	SEE NO. 2.21					
*1.12	LOSS OF TVC ACTUATOR POSITION MECH FEEDBACK BIAS SPRING	OPEN	8	PROVIDE POSITIVE CAGING OF BIAS SPRING	NASA INDICATES REDESIGN IS TAKING PLACE	
*1.13	TRANSIENT LOAD RELIEF VALVE SEAL NO. 1 FAILURE	OPEN	4	PROVIDE BARRIER SEAL	NASA INDICATES BARRIER SEAL IS TO BE ADDED	
*1.14	APU OVERSPEED	OPEN	3	DELETE REQUIREMENT FOR OVERSPEED		

SFP SUMMARY
ORBITER

NO.	ITEM	STATUS	QTY OF SFP'S	REMARKS	RESPONSE	EFFECTIVITY
2.0	ORBITER COMPONENTS					
2.1	ORBITER HYDRAULIC PUMP PRESS RIPPLE NOT COMPLETELY IDENTIFIED	OPEN	3	NEED ADDITIONAL TEST DATA		
2.2	ORBITER HYDRAULIC PUMP CASE DRAIN LINE SURGES MAY EXCEED PUMP CASE OR SHAFT SEAL STRENGTH LIMITS	OPEN	3	NEED ADDITIONAL TEST DATA		
2.3	ABRUPT LINE SIZE REDUCTION AT "T" FITTINGS	OPEN	MANY	STEP DOWN LINE SIZE IN SMALLER INCREMENTS		
*2.4	HYDRAULIC FLUID LEAKAGE EFFECTS ON TPS AND HYDRAZINE LINE INSULATION	OPEN	MANY	A. PROVIDE LEAKAGE SUMPS AND SEAL FAYING SURFACES OF FUSELAGE SKIN B. LOCKWIRE TUBE FITTINGS C. IMPROVE HYDRAZINE LINE SHIELDS		
2.5	HYDRAULIC FLUID LEAKAGE ON HOT APU EXHAUST	OPEN	3	PROVIDE CONVOLUTED SCREEN TO PREVENT DIRECT IMPINGEMENT OF FLUID ON HOT SURFACES		
2.6	FREON LEAKAGE INTO HYDRAULIC SYSTEM	OPEN	MANY	TEST EACH HEAT EXCHANGER		
2.7	ORBITER WHEEL BRAKE HOSES AND PIPING BREAKAGE	OPEN	SFC-2	RELOCATE ONE PAIR TO FORWARD SIDE OF SHOCKSTRUT		
*2.8	LEAKS FROM BRAKE CONTROL MANIFOLD BETWEEN SWITCHING VALVE AND FLOW LIMITER	OPEN	MANY	A. BACKUP LEE PLUGS B. ADD BARRIER TO SEALS C. PERFORM DAMAGE TOLERANCE ANALYSIS D. LOCKWIRE PLUGS AND CAPS		
2.9	POWER VALVE JAMMED SSME-TVC, ELEVON, R/SB, BODY FLAP	OPEN	19	ADD INLET SCREENS AND JAMPROOF VALVES		
*2.10	PISTON ROD BEARING/GLAND RETENTION – ELEVON, TVC ACTUATORS	OPEN	20	PROVIDE POSITIVE LOCK		
*2.11	R/SB MANIFOLD UNION SEALS	OPEN	16	RELIEVE SURFACE TO MINIMIZE SEPARATING FORCE TEST	NASA INDICATES REDESIGN IS TAKING PLACE	
2.12	R/SB BRAKE FAILURE OFF	OPEN	6	PROVIDE REDUNDANT BRAKE MECHANISM		
2.13	RUPTURE OF HYDR PRESS AND RET LINES TO R/SB MOTOR	OPEN	12	ADD NO-BAK TO OUTPUT SHAFT		

SFP SUMMARY
ORBITER

NO.	ITEM	STATUS	QTY OF SFP'S	REMARKS	RESPONSE	EFFECTIVITY
2.14	BODY FLAP BRAKE FAILURE	OPEN	3	PROVIDE REDUNDANT BRAKE MECHANISM		
•2.15	R/SB MODULE, TVC AND ELEVON ACTUATORS NEED FRACTURE CONTROL VERIFICATION	OPEN	11	IMPLEMENT AS SOON AS POSSIBLE		
2.16	PRESSURE VESSEL FAILURES DOWNSTREAM OF SWITCHING VALVE. R/SB	OPEN	24 (+84 BOLTS)	PDU REDESIGN (PER DAC)		
2.17	ELEVON ACTUATORS – INADEQUATE RATE AND FAILURES DOWNSTREAM OF SWITCHING VALVE	OPEN	76 (+312 BOLTS)	ELEVON REDESIGN (PER DAC)		
•2.18	LOSS OF TVC ACTUATOR POSITION MECH FEEDBACK BIAS SPRING	OPEN	12	PROVIDE POSITIVE CAGING OF BIAS SPRING	NASA INDICATES REDESIGN IS TAKING PLACE	
•2.19	R/SB, ELEVON, AND TVC FILTER INDICATOR SEAL FAILURE	OPEN	12	PROVIDE METALLIC BARRIER	NASA INDICATES REDESIGN IS TAKING PLACE	
•2.20	R/SB, ELEVON, AND TVC SERVO VALVE FACE SEAL FAILURE	OPEN	144	UNDERCUT SURFACE TO MINIMIZE LOAD BUILDUP BETWEEN FACES	NASA INDICATES REDESIGN IS TAKING PLACE	
•2.21	SINGLE EXPLOSIVE EVENT NEAR STATION 1307 CAN LOSE 3 SYSTEMS	OPEN	SFC (MANY)	REGROUP SYSTEMS ON STA 1307 AND PROVIDE BARRIERS		

APPENDIX B

SPACE SHUTTLE HYDRAULIC SYSTEM ASSESSMENT FINAL PRESENTATION CHARTS

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SPACE SHUTTLE ASSESSMENT

SPACE SHUTTLE HYDRAULIC SYSTEM ASSESSMENT

NASA HEADQUARTERS PRESENTATION
WASHINGTON, D.C.
JULY 11,1978

MCDONNELL DOUGLAS

SPACE SHUTTLE ASSESSMENT

AGENDA SPACE SHUTTLE HYDRAULIC SYSTEM ASSESSMENT

INTRODUCTION	R. D. WHITE
CHARTER	R. D. WHITE
ASSESSMENT	D. F. GREENE AND STAFF
SUMMARY	D. F. GREENE

CHARTER

- ASSESS ORBITER AND SRB HYDRAULIC SYSTEMS
  - BASELINED ON OFT 102 CONFIGURATION
  - EMPHASIS IS ON OPERATIONAL SHUTTLE
- ASSESS POTENTIAL FOR LOSS OF SHUTTLE DUE TO HYDRAULIC SYSTEM FAILURES
- IDENTIFY CRITICALITY CATEGORY I ITEMS
  - SINGLE FAILURE POINTS (SFP)
  - SINGLE FAILURE CONDITIONS (SFC)
- RECOMMEND CORRECTIVE ACTION

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SPACE SHUTTLE HYDRAULIC SYSTEM ASSESSMENT

INTRODUCTION

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SPACE SHUTTLE HYDRAULIC SYSTEM ASSESSMENT

- ASSESSMENT TEAM
- SCHEDULE
- OBJECTIVES
- TECHNICAL ASSESSMENT
- SUMMARY

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MDC ASSESSMENT TEAM

J. A. CHAMBERLIN	MDC TECHNICAL DIRECTION
D. F. GREENE	PRINCIPAL ENGINEER
D. M. BECK	RELIABILITY AND SAFETY
D. E. EVANS	POWER SYSTEMS
C. H. GOLDTHORPE	SERVOACTUATORS
J. LITTLE	SYSTEM ARCHITECTURE

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SPACE SHUTTLE ASSESSMENT

SCHEDULE

SPACE SHUTTLE HYDRAULIC SYSTEMS ASSESSMENT

TASK	TASK DESCRIPTION OR MILESTONE	1977					1978							
		A	S	O	N	D	J	F	M	A	M	J	J	A
I	ORIENTATION AND DATA COLLECTION				△									
II	REVIEW DATA AND IDENTIFY PROBLEMS								△					
III	DEVELOP CORRECTIVE CONCEPTS							△						
IV	BRIEFINGS AND REPORTS												△	
	MILESTONES	▲ 1	▲ 2	▲ 3			△ 4	▲ 4				▲ 5 △ 6	▲ 6 △ 7	△ 7

1. ORIENTATION AT JSC AND MSFC
2. ORIENTATION AT RI
3. START ASSESSMENT
4. MIDTERM BRIEFING AT JSC
5. FINAL BRIEFING AT JSC 6/23/78
6. FINAL BRIEFING AT HQ 7/11/78
7. FINAL REPORT SUBMITTED 8/11/78

NOTE: DOTTED SYMBOLS △ INDICATE ORIGINAL MILESTONES.

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SPACE SHUTTLE ASSESSMENT

OBJECTIVES OF ASSESSMENT TEAM

- IDENTIFY CRITICAL ASPECTS OF SPACE SHUTTLE NOT NORMALLY ACCEPTABLE IN AIRCRAFT DESIGN
- IDENTIFY SINGLE FAILURE POINTS (SFP) THAT RESULT IN A CRITICALITY CATEGORY I CONDITION
- FOR AREAS THAT DO NOT CONFORM, CONSIDER AND EVALUATE ALTERNATE DESIGN CONCEPTS
  - COST IMPACT
  - SCHEDULE IMPACT
- ARCHITECTURE ASSESSMENT EVALUATION
  - HORSEPOWER REQUIREMENTS
  - SYSTEM REDUNDANCY
  - SYSTEM ARRANGEMENT

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SPACE SHUTTLE ASSESSMENT

HARDWARE REVIEWED

SOLID ROCKET BOOSTER
- HYDRAULIC POWER SYSTEM
  - PUMP
  - FLUID MANIFOLD
  - FILTER
  - RESERVOIR
  - QUICK DISCONNECT FITTING
  - MANUAL SHUTOFF VALVE
  - CHECK VALVE
  - LINES AND FITTINGS
  - HOSES

ORBITER
- HYDRAULIC POWER SYSTEM
  - PUMP
  - RESERVOIR
  - RELIEF VALVE
  - FILTER MODULE
  - ACCUMULATOR
  - ACCUMULATOR PRIORITY VALVE
  - MANUAL DUMP VALVE
  - PRESSURE ACTUATED CONTROL VALVE
  - CIRCULATION PUMP
  - BYPASS RELIEF VALVE
  - OIL/FREON HEAT EXCHANGER
  - THERMAL CONTROL VALVE
  - QUICK DISCONNECT
  - PRESSURE TRANSDUCER
  - TEMPERATURE TRANSDUCER
  - CHECK VALVE
  - HOSE

MAIN ENGINE GIMBAL ACTUATION
- QUICK DICONNECT
- HOSE
- CHECK VALVE

RUDDER/SPEEDBRAKE
- OLEOPHOBIC FILTER
- SHAFT SEAL DRAIN MANIFOLD
- HOSE

BODY FLAP
- HYDRAULIC MOTOR
- OLEOPHOBIC FILTER
- SHAFT SEAL DRAIN MANIFOLD
- HOSE

ACTUATOR, UMBILICAL RETRACTOR
- ACTUATOR
- HOSE
- MANIFOLD

MAIN LANDING GEAR
- UPLOCK ACTUATOR
- MAIN LANDING GEAR ACTUATOR
- ISOLATION VALVE
- CONTROL VALVE
- DUMP VALVE
- RETRACT CYLINDER
- MANIFOLD ASSY
- FILTER
- HOSE
- UP/CIRCULATION VALVE
- CHECK VALVE

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SPACE SHUTTLE ASSESSMENT

HARDWARE REVIEWED

WHEELS AND BRAKES
- PRESSURE REGULATOR
- BRAKE CONTROL VALVE MODULE
- BRAKE ASSEMBLY
- HOSE
- WHEEL ASSEMBLY
- PRESSURE TRANSDUCER
- QUICK DISCONNECT

NOSE LANDING GEAR
- LANDING GEAR ACTUATOR
- UPLOCK ACTUATOR
- MANIFOLD
- CYLINDER

NOSE WHEEL STEERING
- STEERING AND DAMPING ACTUATOR

SRB-TVC ACTUATOR
- SERVOVALVE
- DYNAMIC PRESSURE FEEDBACK MODULE
- SERVOVALVE ΔP SENSOR
- SWITCHING VALVE
- POWER VALVE
- LOCK VALVE
- TRANSIENT LOAD RELIEF VALVE
- PISTON ROD
- CYLINDER
- ACTUATOR POSITION FEEDBACK MECHANISM
- INLET FILTER
- SOLENOID ISOLATION VALVE
- LOAD PRESSURE TRANSDUCER

SSME-TVC ACTUATOR
- SERVOVALVE
- DYNAMIC PRESSURE FEEDBACK MODULE
- SERVOVALVE ΔP SENSOR
- SWITCHING VALVE
- POWER VALVE
- FORCE LIMITER VALVE
- PISTON ROD
- CYLINDER
- ACTUATOR POSITION FEEDBACK MECHANISM
- INLET FILTER
- FILTER ΔP INDICATOR
- SOLENOID ISOLATION VALVE
- LOCK VALVE
- LOAD ΔP TRANSDUCER

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HARDWARE REVIEWED

ELEVON ACTUATOR
- SERVOVALVE
- SERVOVALVE ΔP SENSOR
- SWITCHING VALVE
- POWER VALVE
- PISTON ΔP SENSOR
- PISTON ROD
- CYLINDER
- ACTUATOR PISTON LVDT
- INLET FILTER
- FILTER ΔP INDICATOR
- SOLENOID ISOLATION VALVE

R/SB HYDRAULIC CONTROL MODULE
- SERVOVALVE
- SERVOVALVE ΔP SENSOR
- SWITCHING VALVE
- TRIPLEX POWER VALVE
- INLET FILTER
- FILTER ΔP INDICATOR
- SOLENOID ISOLATION VALVE
- HYDRAULIC MOTOR/BRAKE

B/F HYDRAULIC CONTROL MODULE
- ENABLE SOLENOID
- PILOT UP COMMAND SOLENOID
- PILOT DOWN COMMAND SOLENOID
- POWER VALVE
- HYDRAULIC MOTOR/BRAKE

SSME FUEL VALVES
- SERVOVALVE
- SHUTTLE VALVE
- BYPASS VALVE
- FAIL-OPERATE SERVOSWITCH
- FAILSAFE SERVOSWITCH
- ROTARY ACTUATOR
- RVDT

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TECHNICAL ASSESSMENT

• FAULT TREE ANALYSIS	D. M. BECK
• IDENTIFIES CRITICALITY CATEGORY 1	
• SINGLE FAILURE POINTS (SFP)	
• QUALITATIVE TOOL	
• HYDRAULIC POWER AND UTILITY SYSTEMS	D. E. EVANS
• SERVOCONTROL SYSTEMS	C. H. GOLDTHORPE
• SYSTEM ARCHITECTURE	J. LITTLE

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SPACE SHUTTLE ASSESSMENT

FAULT TREE ANALYSIS

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SPACE SHUTTLE ASSESSMENT

SPACE SHUTTLE FAULT TREE ANALYSIS

PURPOSE:

TO ASSURE ALL SINGLE-FAILURE-POINT (CRITICALITY CATEGORY I)* HAZARDS ARE IDENTIFIED

- ORDERLY, LOGICAL ANALYSIS METHOD
- PROVIDES OVERALL VISIBILITY — RELATIONSHIPS AND QUANTITY OF HAZARDS

ANALYTICAL TOOL TO ASSIST ASSESSMENT

SCOPE:

ALL SRB/ORBITER HYDRAULIC SYSTEM EFFECTORS

QUALITATIVE ANALYSIS

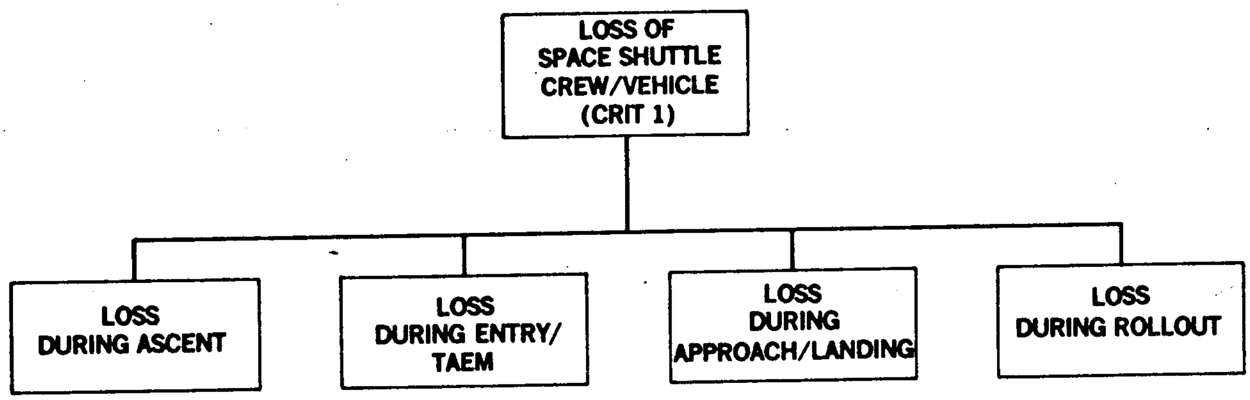
BASED ON FMEA'S, SAR'S, HA'S, OTHER REVIEWS AND STUDIES, AND PARTICULARLY OUR ASSESSMENT OF THE SYSTEM/EQUIPMENT

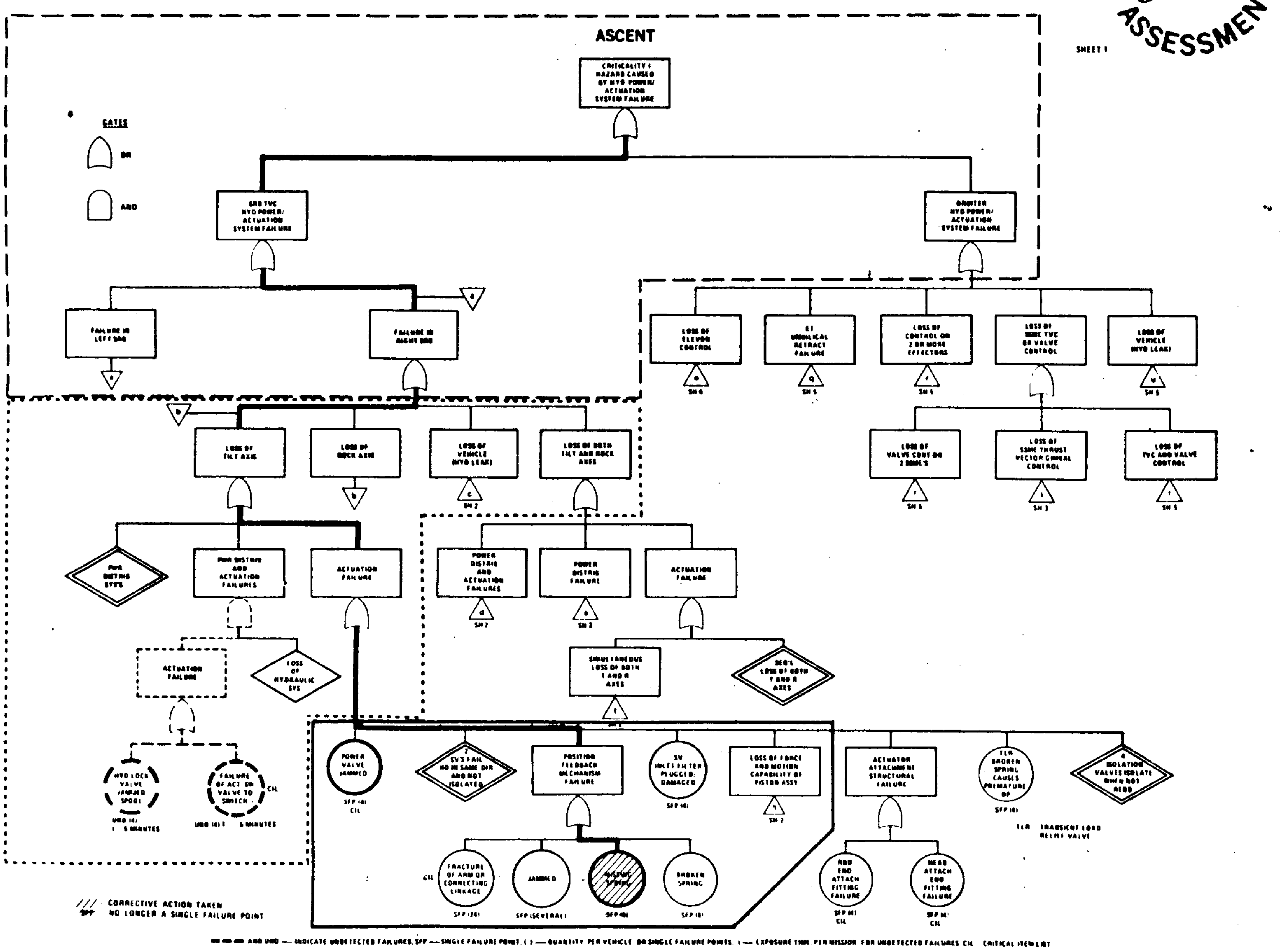
MISSION PHASES

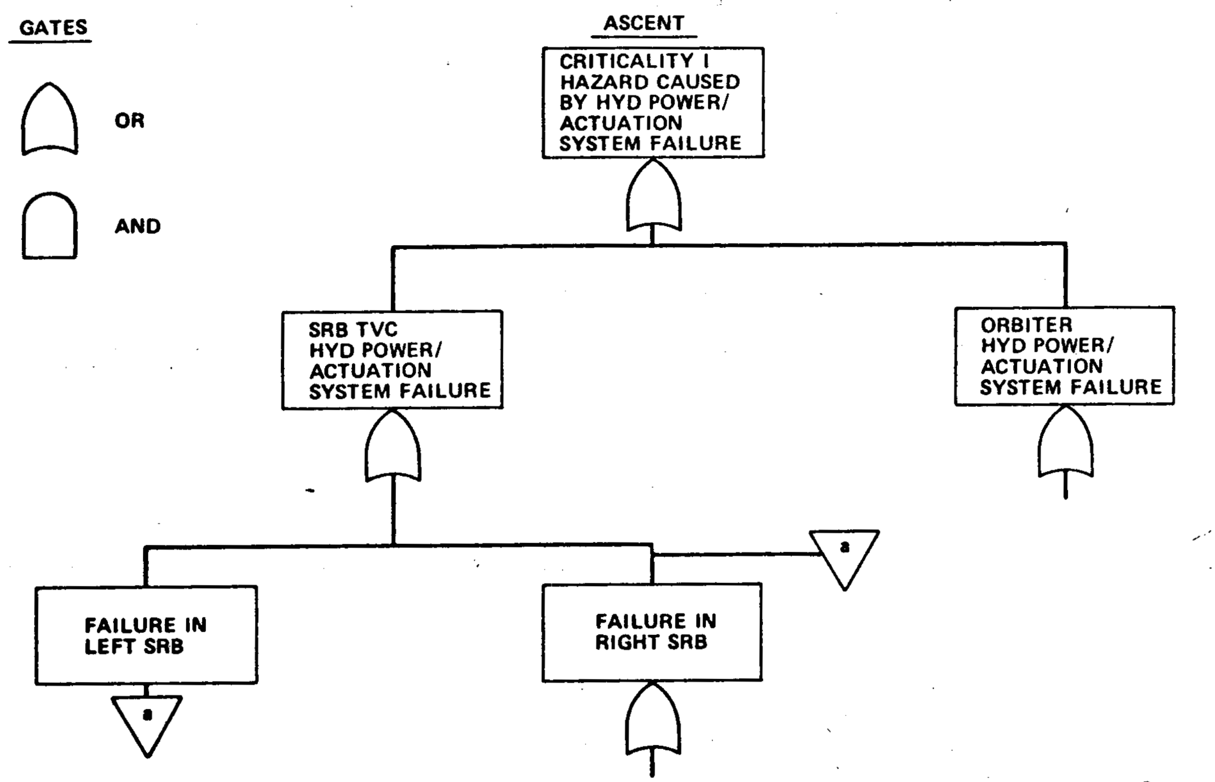
- ASCENT
- ENTRY/TAEM
- APPROACH/LANDING
- ROLLOUT

* LOSS OF VEHICLE/CREW

FAULT TREE DIVISIONS




SHEET 1
ASCENT
CRITICALITY 1 HAZARD CAUSED BY HYD POWER/ ACTUATION SYSTEM FAILURE
GATES
OR
AND
SRB TVC HYD POWER/ ACTUATION SYSTEM FAILURE
ORBITER HYD POWER/ ACTUATION SYSTEM FAILURE
FAILURE IN LEFT SRB
FAILURE IN RIGHT SRB
LOSS OF ELEVON CONTROL
ET UMBILICAL RETRACT FAILURE
LOSS OF CONTROL OR 2 OR MORE EFFECTORS
LOSS OF SSME TVC OR VALVE CONTROL
LOSS OF VEHICLE (HYD LEAK)
LOSS OF VALVE CONT OR 2 SSME'S
LOSS OF SSME THRUST VECTOR GIMBAL CONTROL
LOSS OF TVC AND VALVE CONTROL
LOSS OF TILT AXIS
LOSS OF ROCK AXIS
LOSS OF VEHICLE (HYD LEAK)
LOSS OF BOTH TILT AND ROCK AXES
PWR DISTRIB SYS
PWR DISTRIB AND ACTUATION FAILURES
ACTUATION FAILURE
POWER DISTRIB AND ACTUATION FAILURES
POWER DISTRIB FAILURE
ACTUATION FAILURE
ACTUATION FAILURE
LOSS OF HYDRAULIC SYS
SIMULTANEOUS LOSS OF BOTH T AND R AXES
SEQ'L LOSS OF BOTH T AND R AXES
HYD LOCK VALVE JAMMED SPOOL
FAILURE OF ACT SW VALVE TO SWITCH
POWER VALVE JAMMED
SFP (4) CIL
2 SV'S FAIL NO IN SAME DIR AND NOT ISOLATED
POSITION FEEDBACK MECHANISM FAILURE
SV INLET FILTER PLUGGED: DAMAGED
SFP (4)
LOSS OF FORCE AND MOTION CAPABILITY OF PISTON ASSY
ACTUATOR ATTACHMENT STRUCTURAL FAILURE
TLR BROKEN SPRING CAUSES PREMATURE OP
SFP (4)
4 ISOLATION VALVES ISOLATE WHEN NOT REQD
TLR TRANSIENT LOAD RELIEF VALVE
FRACTURE OF ARM OR CONNECTING LINKAGE
SFP (24)
JAMMED
SFP (SEVERAL)
BROKEN SPRING
SFP (4)
ROD END ATTACH FITTING FAILURE
SFP (4) CIL
HEAD ATTACH END FITTING FAILURE
SFP (4) CIL
CORRECTIVE ACTION TAKEN NO LONGER A SINGLE FAILURE POINT
AND UND — INDICATE UNDETECTED FAILURES, SFP — SINGLE FAILURE POINT, ( ) — QUANTITY PER VEHICLE OR SINGLE FAILURE POINTS, t — EXPOSURE TIME PER MISSION FOR UNDETECTED FAILURES CIL — CRITICAL ITEM LIST



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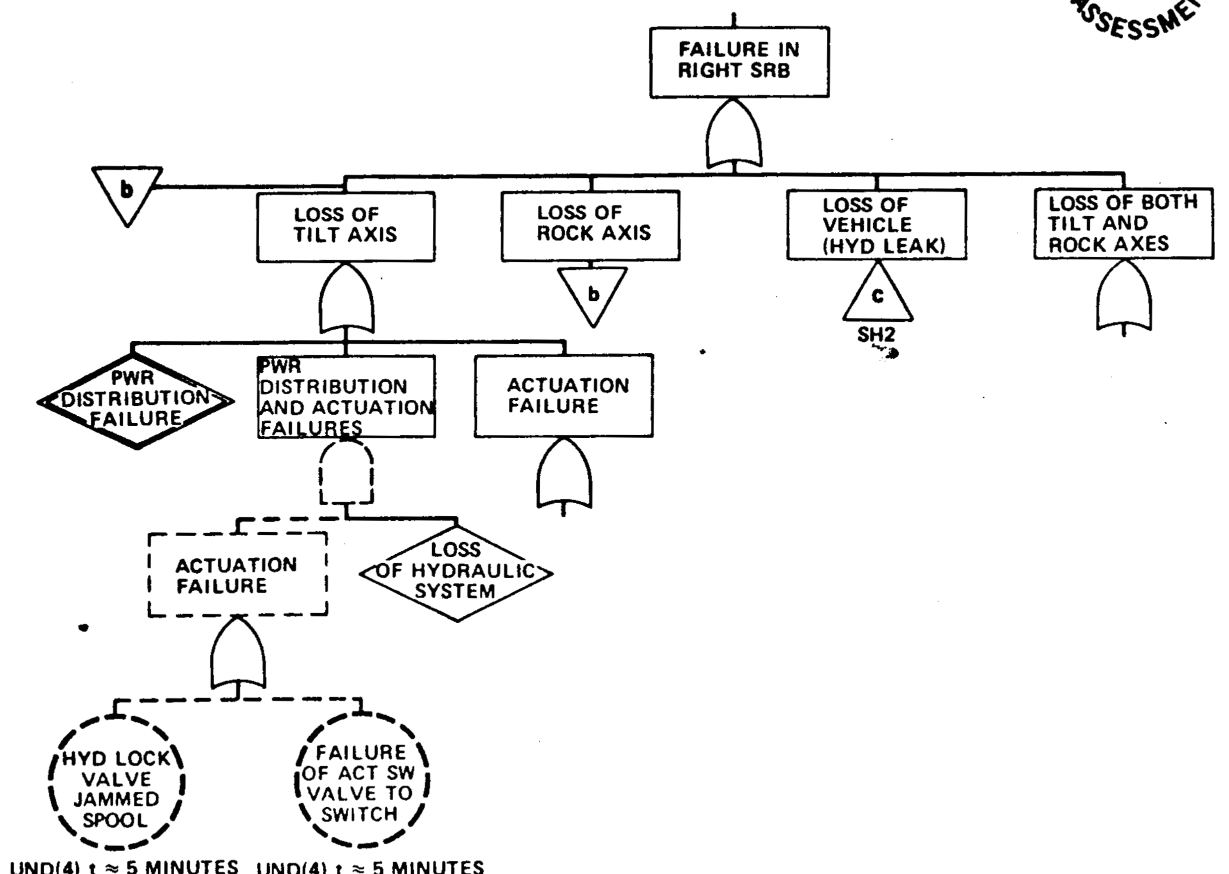
SPACE SHUTTLE ASSESSMENT



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SPACE SHUTTLE ASSESSMENT

SINGLE FAILURE POINT SYMBOLS

— UNDETECTED FAILURE*

— ACCEPTED RISK

— SIGNIFICANT (NOT ACCEPTABLE)

— NO LONGER A SINGLE FAILURE POINT**

— ELIMINATED WITH TANDEM ACTUATOR DESIGN

* UNDETECTABLE/UNKNOWN FAILURE IN FLIGHT WHICH, COMBINED WITH ANOTHER HARDWARE ELEMENT FAILURE, COULD CAUSE LOSS OF LIFE OR VEHICLE

** CORRECTIVE ACTION IS BEING TAKEN

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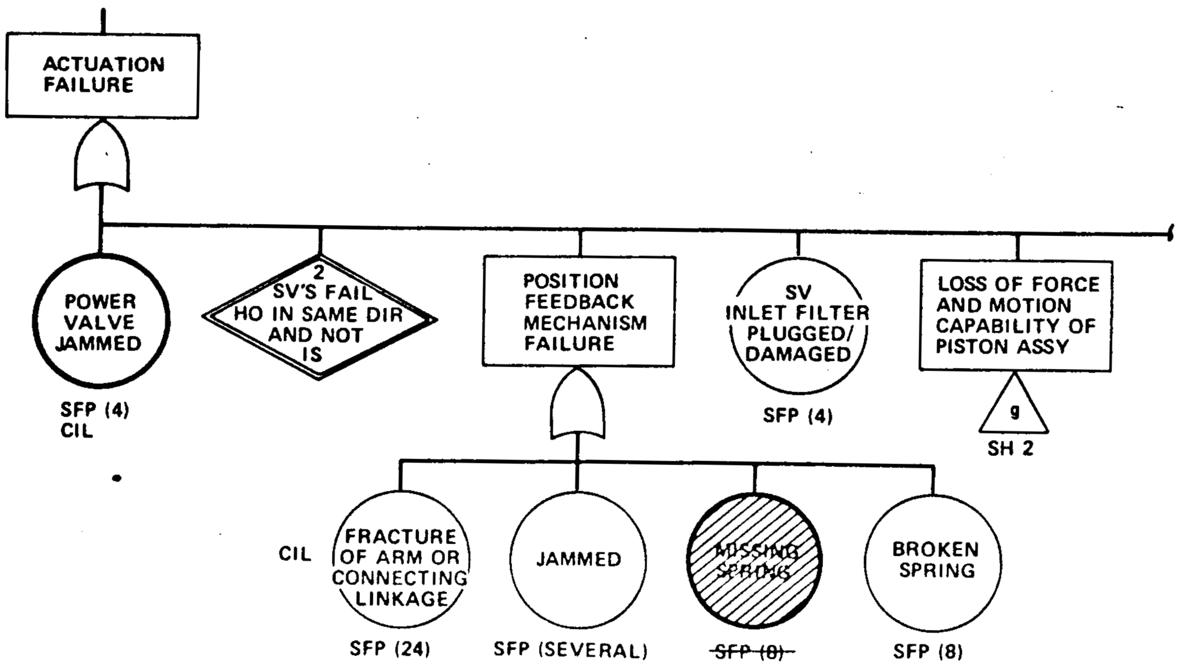
SPACE SHUTTLE ASSESSMENT



CRITICAL CATEGORY 1 SUMMARY

OPEN SIGNIFICANT ITEMS

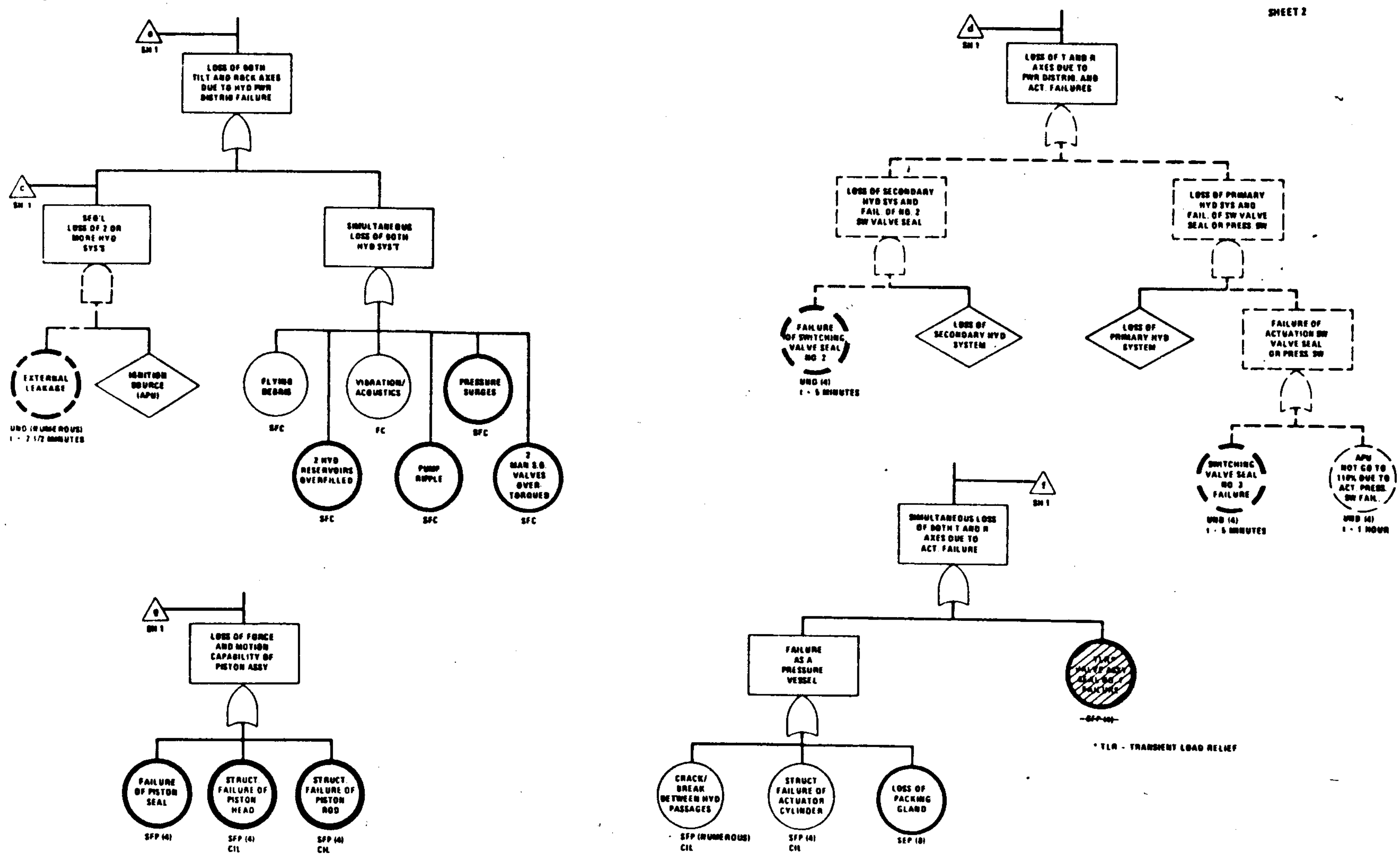
CATEGORY OF FAILURE (CRIT)	POWER DISTRIBUTION		CONTROL ACTUATION		SUBTOTAL		TOTAL
	SRB	ORB	SRB	ORB	SRB	ORB	VEHICLE
SINGLE FAILURE POINT (1)	LEAKS	LEAKS	32	203	32	203	235
UNDETECTED FAILURE (1U)	LEAKS	—	16	13	16	13	29
SINGLE FAILURE CONDITION * (1)	16	9	—	—	16	9	25
TOTALS	16	9	48	216	64	225	289**

* CONDITION THAT IF IT OCCURS CAN RESULT IN LOSS OF TWO OR MORE HYDRAULIC SYSTEMS SIMULTANEOUSLY (E. G. APU FLYING DEBRIS)

** NOT INCLUDING LEAKS

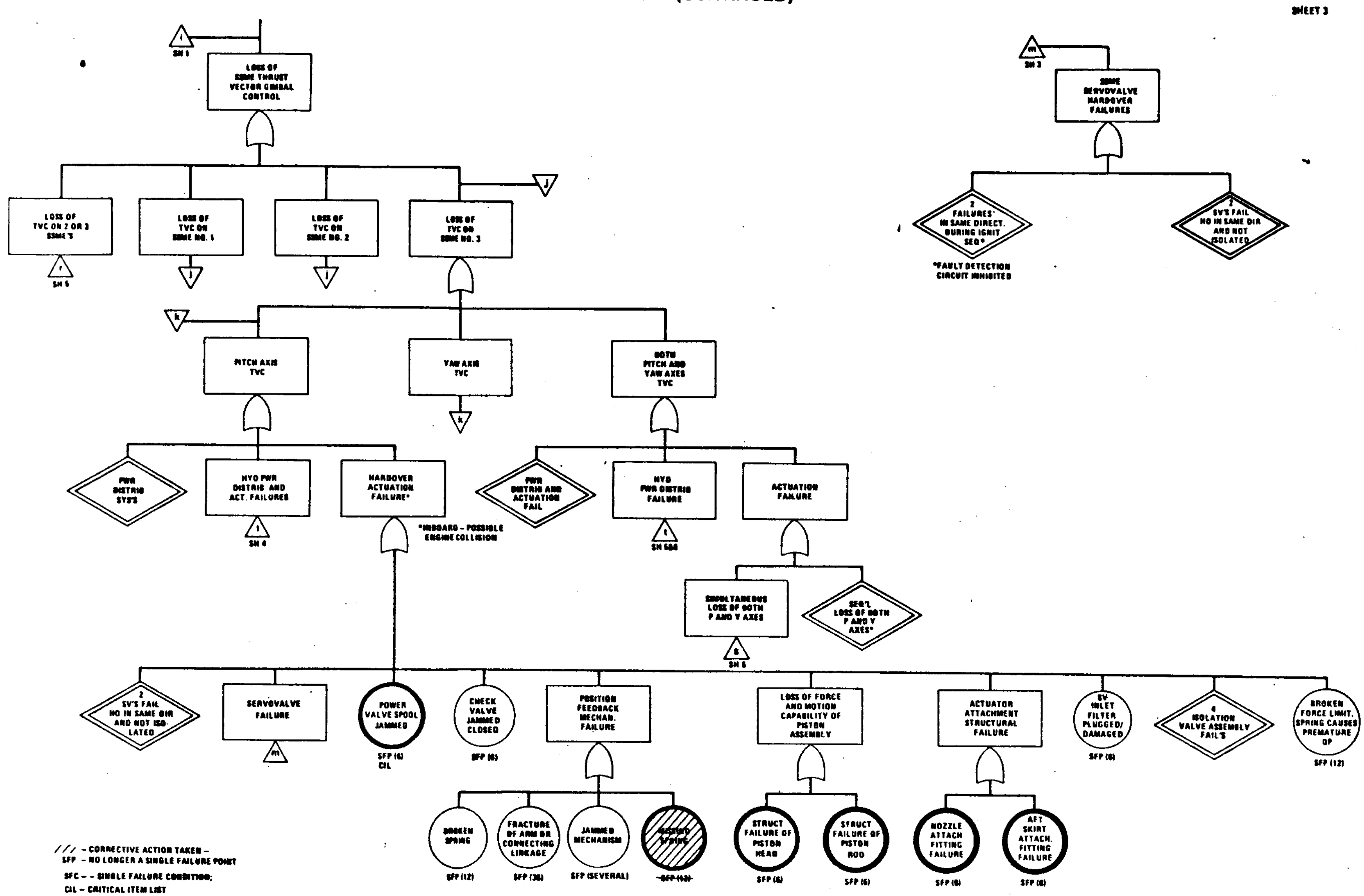
ASCENT (CONTINUED)

SHEET 2



SFC – SINGLE FAILURE CONDITION; ▭ ▭ ▭ AND UND —— INDICATE UNDETECTED FAILURES; I —— EXPOSURE TIME PER MISSION FOR UNDETECTED FAILURES; CIL CRITICAL ITEM LIST

ASCENT (CONTINUED)



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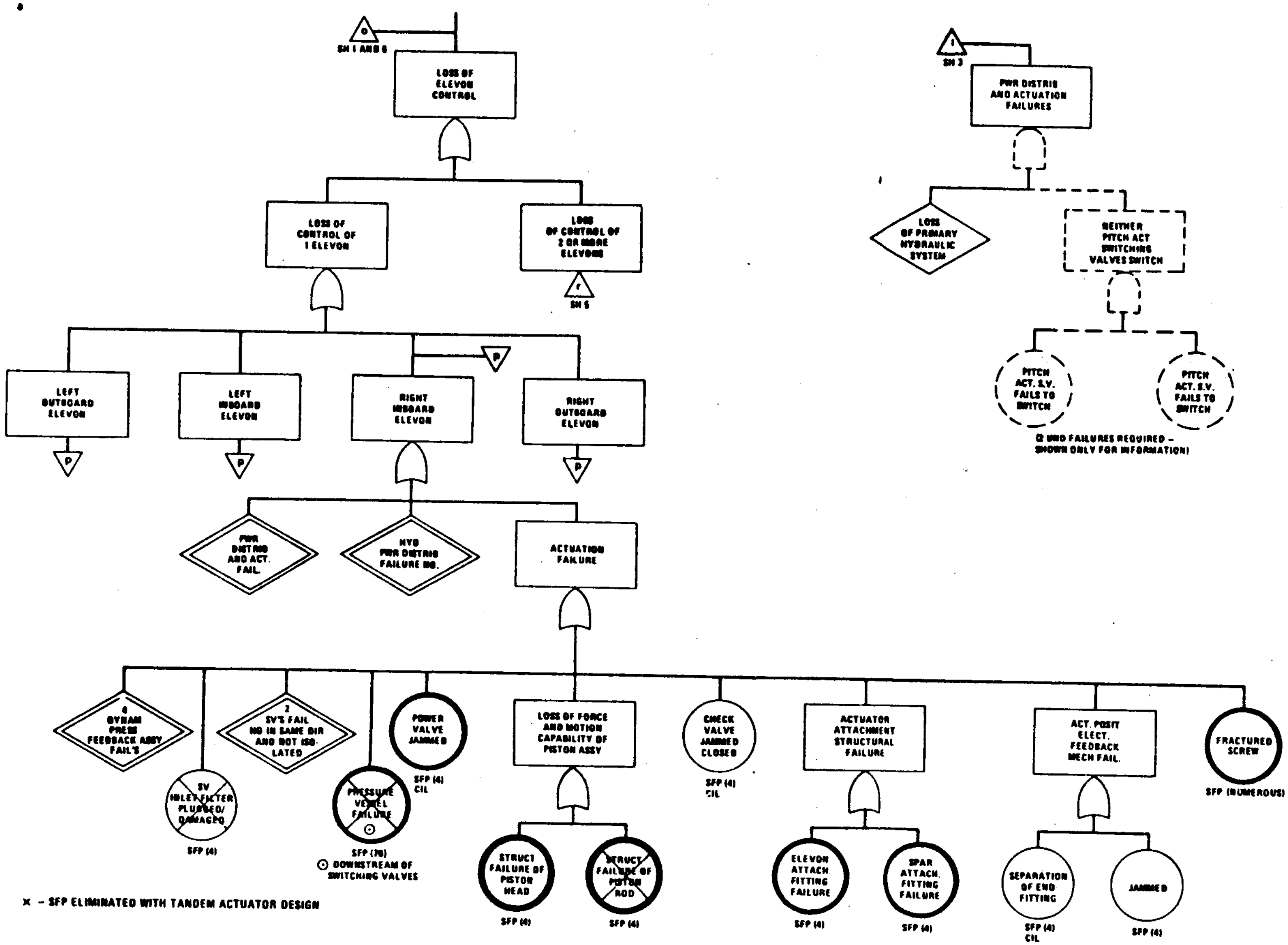
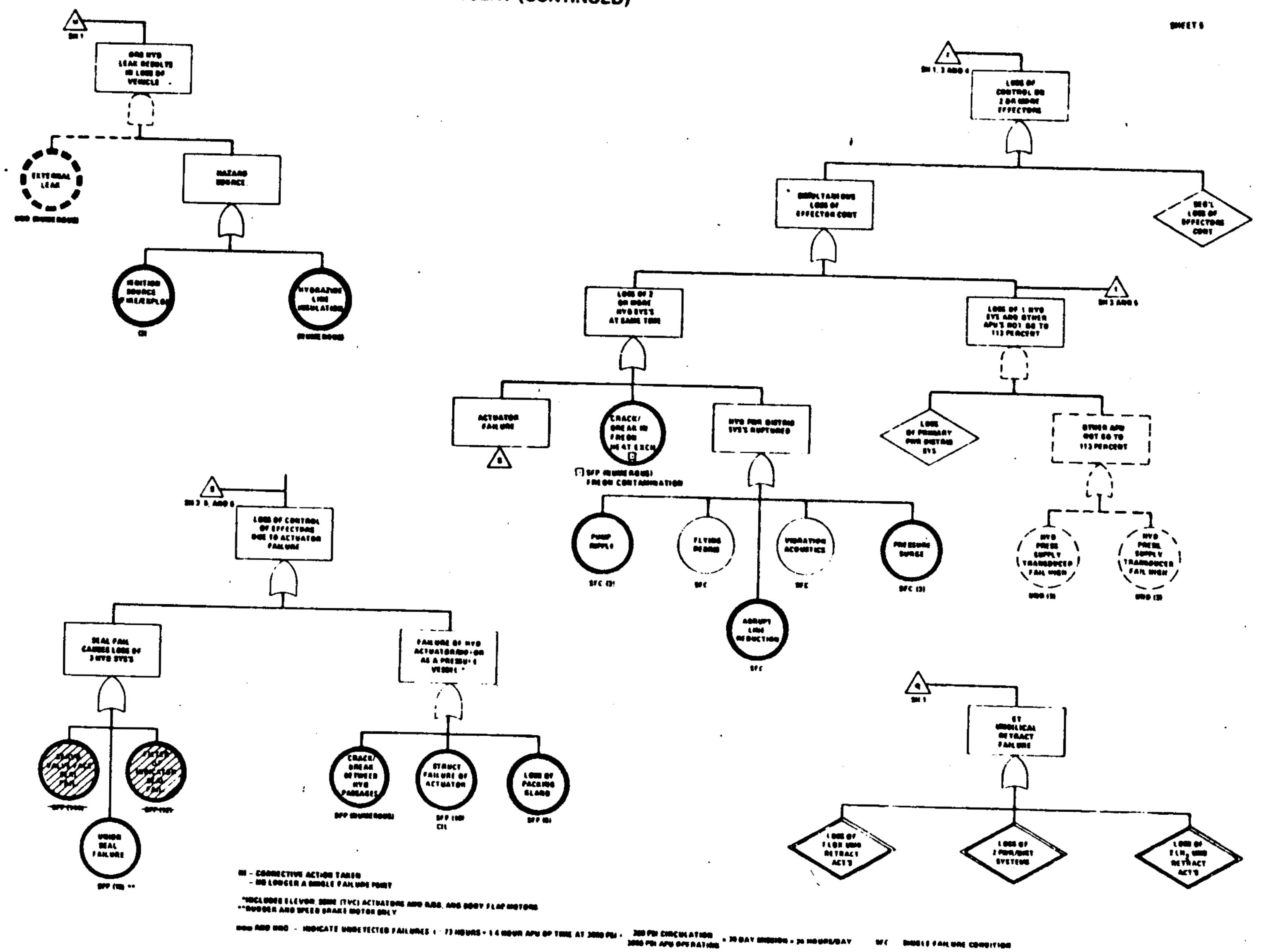
SPACE SHUTTLE ASSESSMENT

SHEET 4

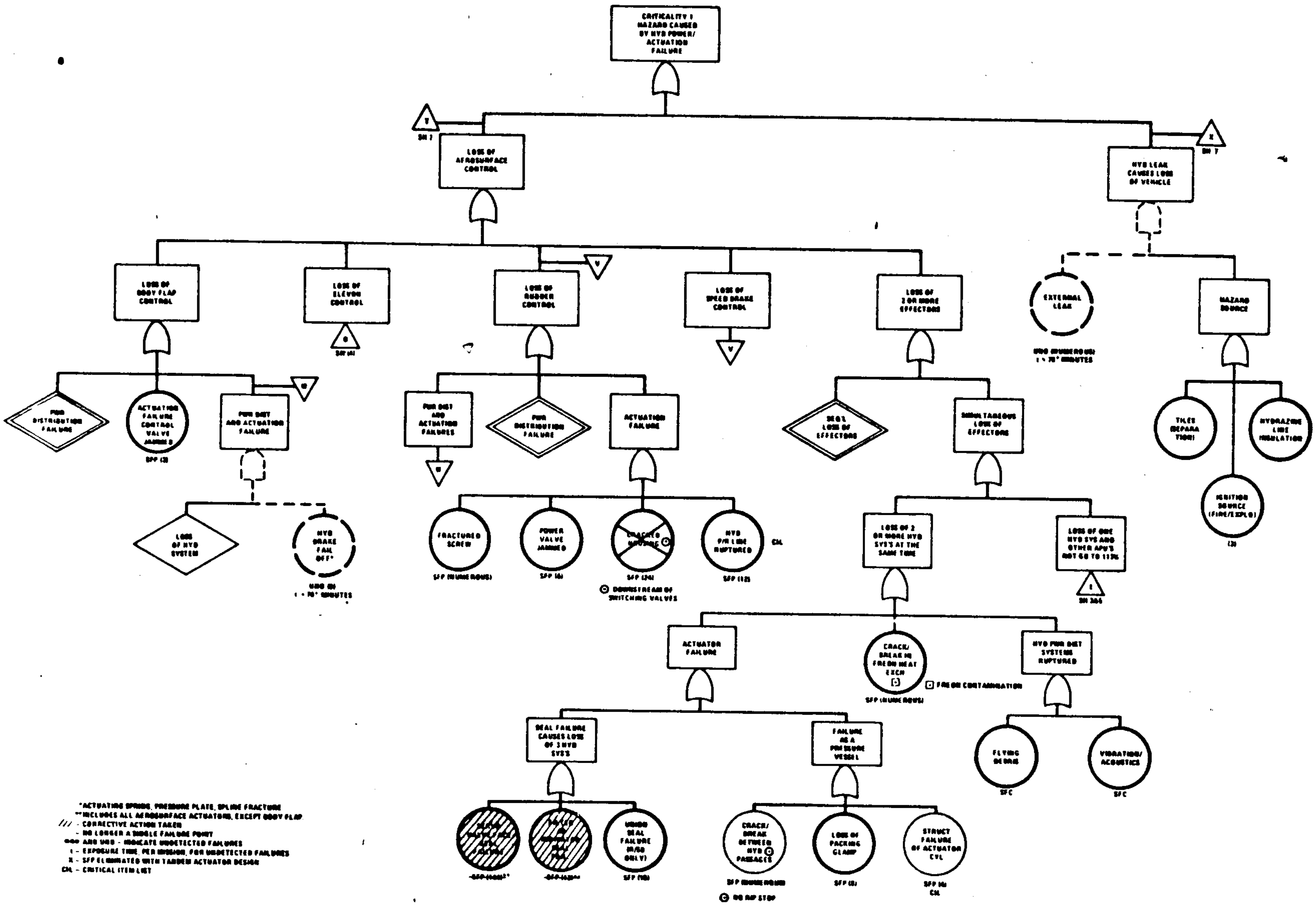
ASCENT (CONTINUED)



ASCENT (CONTINUED)



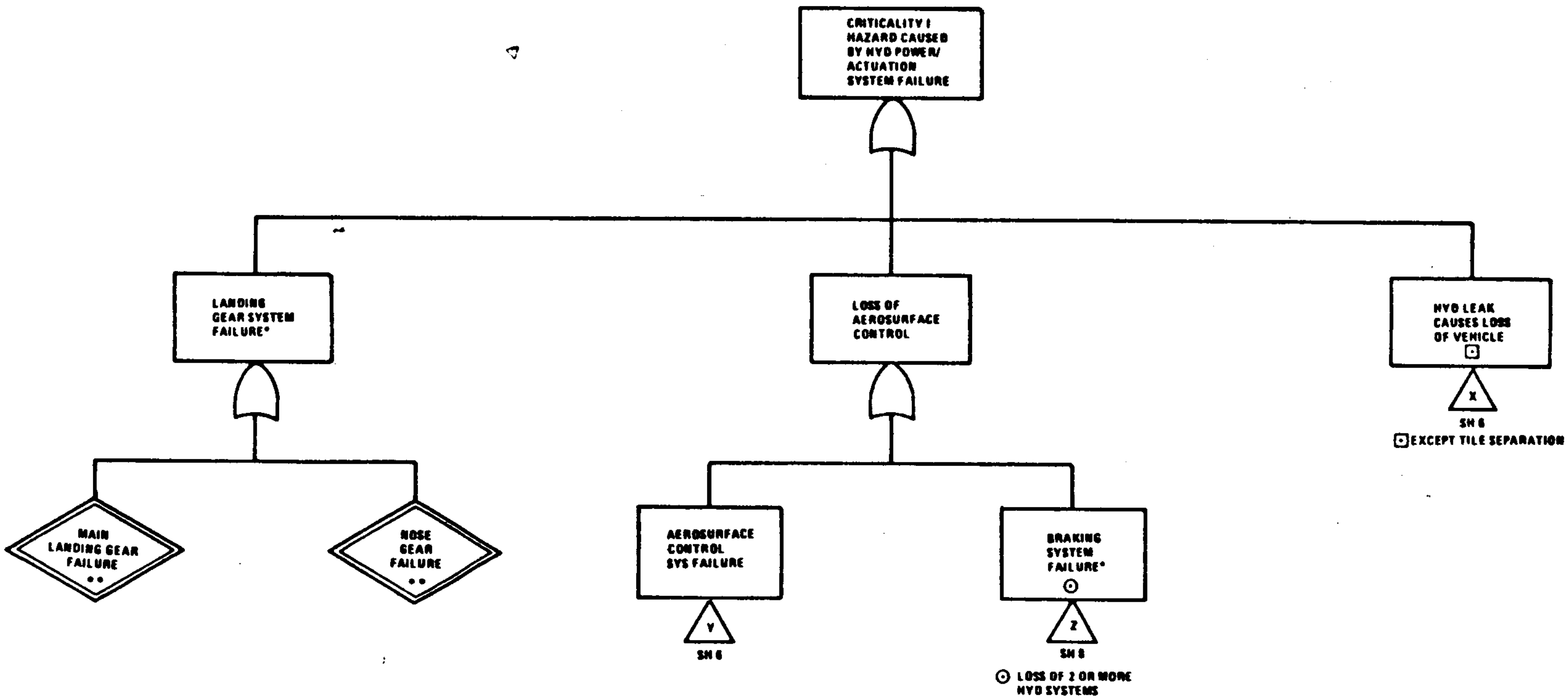
ENTRY AND TAEM



*ACTUATING SPRING, PRESSURE PLATE, SPLINE FRACTURE
**INCLUDES ALL AEROSURFACE ACTUATORS, EXCEPT BODY FLAP
/// - CORRECTIVE ACTION TAKEN
- NO LONGER A SINGLE FAILURE POINT
ARE UHD - INDICATE UNDETECTED FAILURES
t - EXPOSURE TIME, PER MISSION, FOR UNDETECTED FAILURES
X - SFP ELIMINATED WITH TANDEM ACTUATOR DESIGN
CIL - CRITICAL ITEM LIST

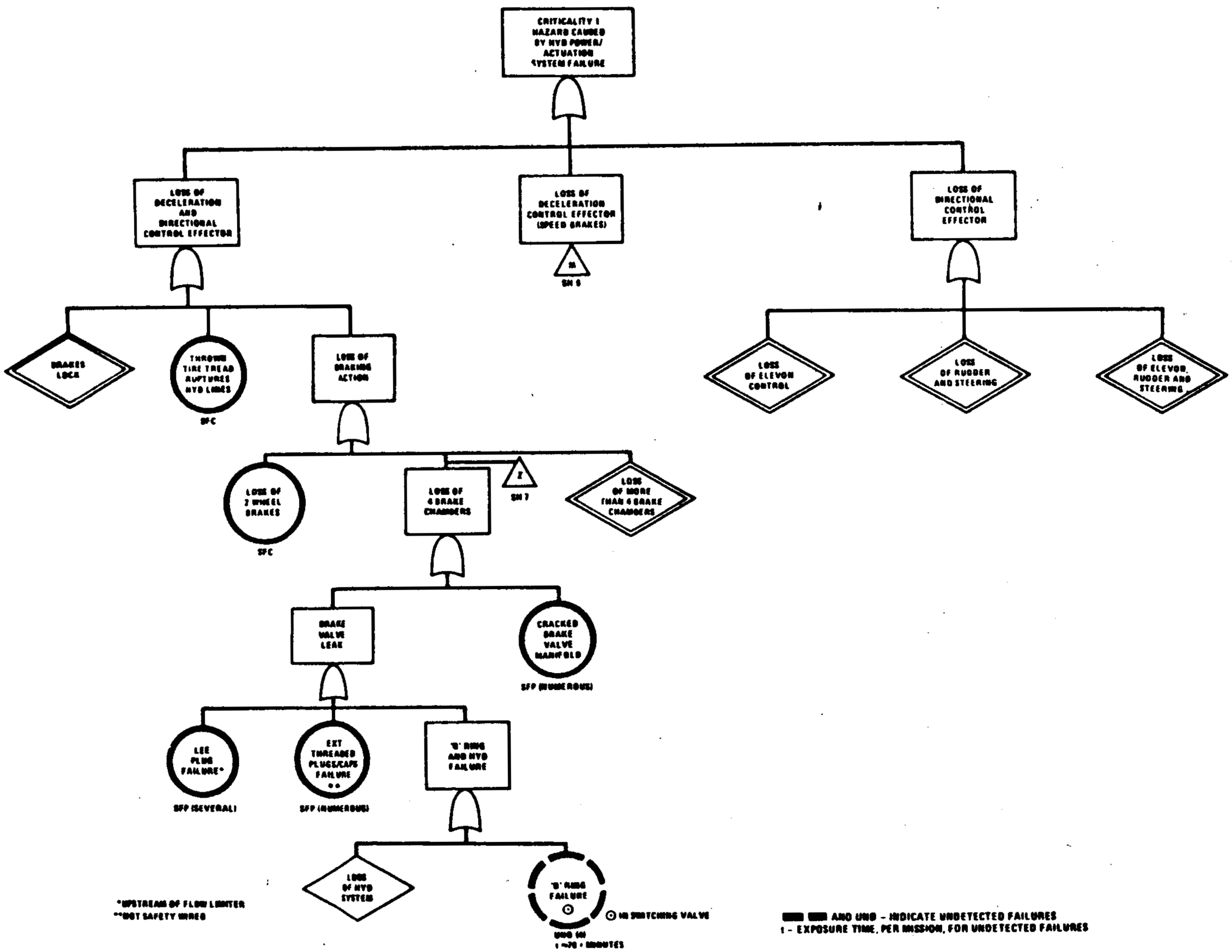
APPROACH AND LANDING

SHEET 7



*SHORT TIME DURATION (LESS THAN ONE MINUTE). SYSTEM ISOLATED PRIOR TO EXTENSION OF LANDING GEAR.
**ORDNANCE UNLATCH PROVISIONS AND FREE FALL CAPABILITY

ROLLOUT


CRITICALITY 1 HAZARD CAUSED BY HYD POWER/ ACTUATION SYSTEM FAILURE
LOSS OF DECELERATION AND DIRECTIONAL CONTROL EFFECTOR
LOSS OF DECELERATION CONTROL EFFECTOR (SPEED BRAKES)
M
SH 8
LOSS OF DIRECTIONAL CONTROL EFFECTOR
BRAKES LOCK
THROWN TIRE TREAD RUPTURES HYD LINES
SFC
LOSS OF BRAKING ACTION
LOSS OF ELEVON CONTROL
LOSS OF RUDDER AND STEERING
LOSS OF ELEVON, RUDDER AND STEERING
LOSS OF 2 WHEEL BRAKES
SFC
LOSS OF 4 BRAKE CHAMBERS
Z
SH 7
LOSS OF MORE THAN 4 BRAKE CHAMBERS
BRAKE VALVE LEAK
CRACKED BRAKE VALVE MANIFOLD
SFP (NUMEROUS)
LEE PLUG FAILURE*
SFP (SEVERAL)
EXT THREADED PLUGS/CAPS FAILURE **
SFP (NUMEROUS)
'O' RING AND HYD FAILURE
LOSS OF HYD SYSTEM
'O' RING FAILURE
UND 1H
t ~70 + MINUTES
IN SWITCHING VALVE
*UPSTREAM OF FLOW LIMITER
**NOT SAFETY WIRED
AND UND - INDICATE UNDETECTED FAILURES
t - EXPOSURE TIME, PER MISSION, FOR UNDETECTED FAILURES

POWER AND UTILITY SYSTEMS ASSESSMENT

POWER AND UTILITY SYSTEMS REVIEW

VEHICLE	SYSTEM	QUANTITY OF CATEGORY 1 ITEMS
SRB	HYDRAULIC POWER SYSTEMS	3
ORBITER	HYDRAULIC POWER SYSTEM	2
	MAIN ENGINE GIMBAL ACT.	—
	ELEVON SYSTEM	—
	RUDDER SPEED BRAKE	—
	BODY FLAP	—
	E T RETRACT ACTUATOR	—
	MAIN LANDING GEAR	—
	WHEELS AND BRAKES	2
	NOSE LANDING GEAR	—
	NOSE WHEEL STEERING	—

POWER AND UTILITY SYSTEMS

SOLID ROCKET BOOSTER PROBLEMS

- RESERVOIR OVERFILLING
- PUMP HOSE AND LINE FATIGUE
- MANUAL SHUT-OFF VALVE

ORBITER PROBLEMS

- HYDRAULIC SYSTEM LEAKAGE
- LEAKAGE OF FREON INTO OIL
- BRAKE PIPE AND HOSE DAMAGE FROM TIRE FAILURE
- BRAKE CONTROL VALVE LEAKAGE

POWER AND UTILITY SYSTEMS

POTENTIAL CATEGORY NO. 1 ITEMS NOT REVIEWED

- WATER SPRAY BOILER
- NOSE GEAR STEERING AND DAMPING SUBSYSTEM

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SRB — RESERVOIR

PROBLEM

- FLUID THERMAL EXPANSION
  (180°F TEMP RISE = +14 PERCENT RESERVOIR VOL)
  RESERVOIR PISTON BOTTOMS
  NO PRESSURE RELIEF
  RESERVOIR BURSTS

RECOMMENDATIONS

- VENT LP RELIEF OVERBOARD
  OR
- LIMIT MAXIMUM OIL FILL VOLUME
- CHECK VOLUME AT COUNTDOWN
- AUTOMATIC LAUNCH HOLD FOR MINIMUM AND MAXIMUM OIL VOLUME

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SRB — PUMP HOSES AND LINES

PROBLEM

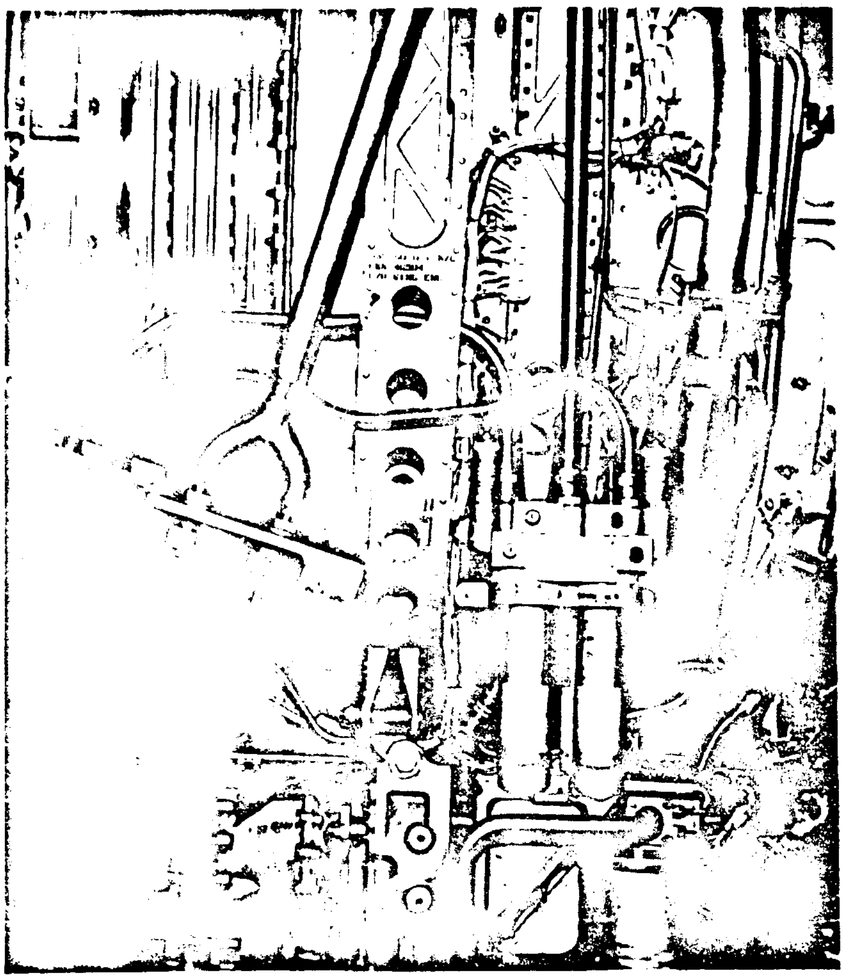
- PUMP PIPING CONFIGURATION SIMILAR TO EARLY DC-10
  LINES FAILED IN 40 HOURS
- LACK OF TEST DATA ON SRB SYSTEM
- DUAL FAILURE PROBABILITY UNACCEPTABLE

RECOMMENDATIONS

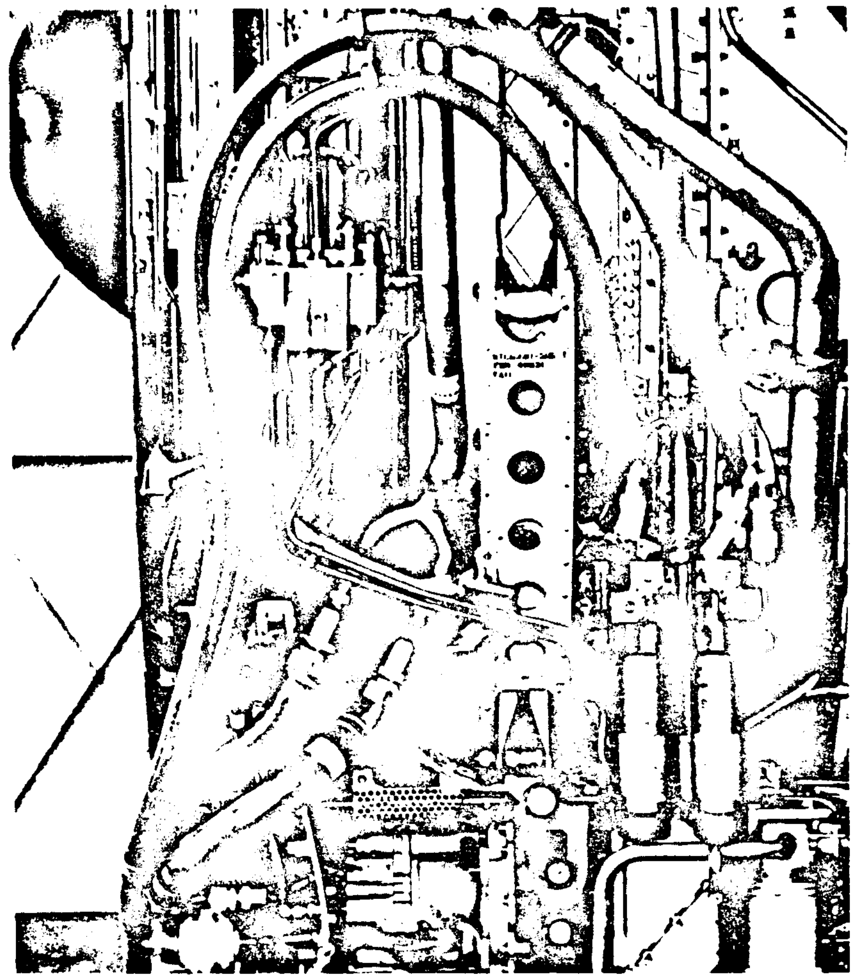
- TEST PROTOTYPE OF PRODUCTION SYSTEM USING
  - KISTLER PRESSURE TRANSDUCERS
  - CONTINUOUS READOUT ON RECORDER
  - LINE ATTENUATOR AND LONGER HOSE IF REQUIRED

DC-10 PUMP PRESSURE LINES

BEFORE



AFTER



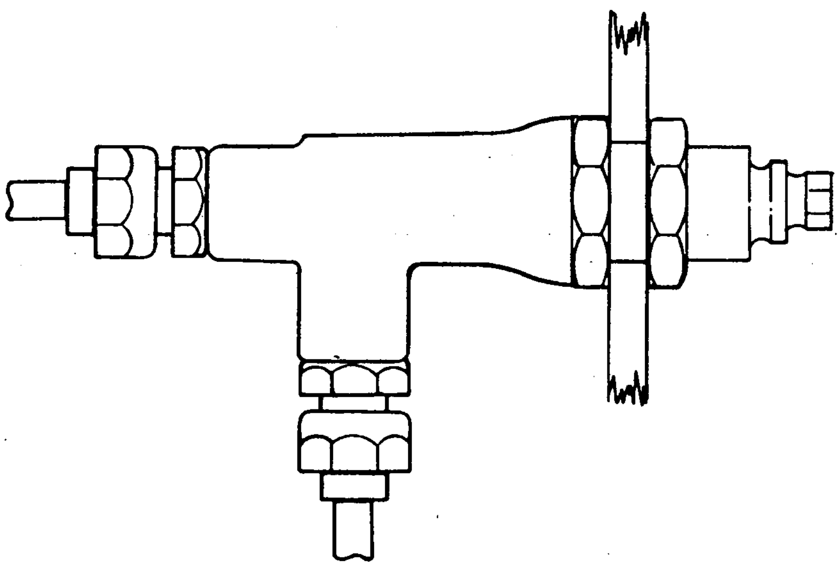
SRB — MANUAL SHUTOFF VALVE

PROBLEM
- VALVE CAN LOOSEN IN SERVICE PANEL
- VALVE MOTION MAY DEFORM OR LOOSEN TUBING

RECOMMENDATION
- PROVIDE ANTI-ROTATION DEVICE BETWEEN VALVE AND SERVICE PANEL LOCK JAM NUT

ACTION TAKEN
- MSFC HAS INCORPORATED POSITIVE LOCK

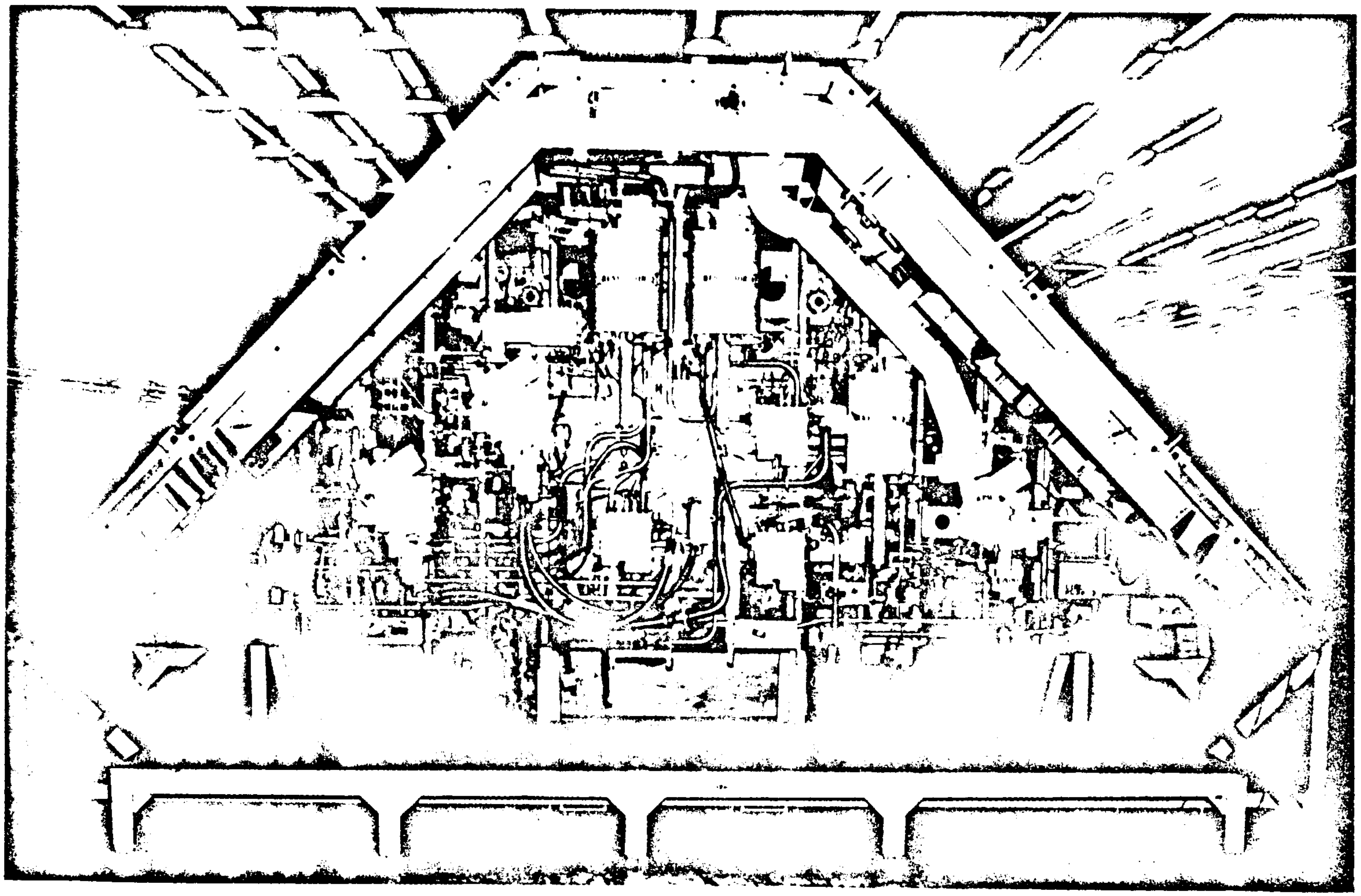
MANUAL SHUTOFF VALVE



ORBITER — HYDRAULIC LEAKAGE
PROBLEM

- EXTERNAL HYDRAULIC LEAKAGE MAKE ORBITER VULNERABLE TO:
  - THERMAL TILE SEPARATION
  - APU FIRES
  - HYDRAZINE LINE FREEZING OR OVERHEATING
- LACK OF SEPARATION OF REDUNDANT POWER SYSTEMS

SYSTEMS AND TUBING INSTALLATION ON ORBITER 1307 BULKHEAD
(MANUFACTURING TOOL)



ORBITER — HYDRAULIC LEAKAGE

PROBLEM

- CONTAINMENT OF TURBINE PUMPS
- VULNERABILITY OF:

  TVC ACTUATORS

  BODY FLAP CONTROL VALVE

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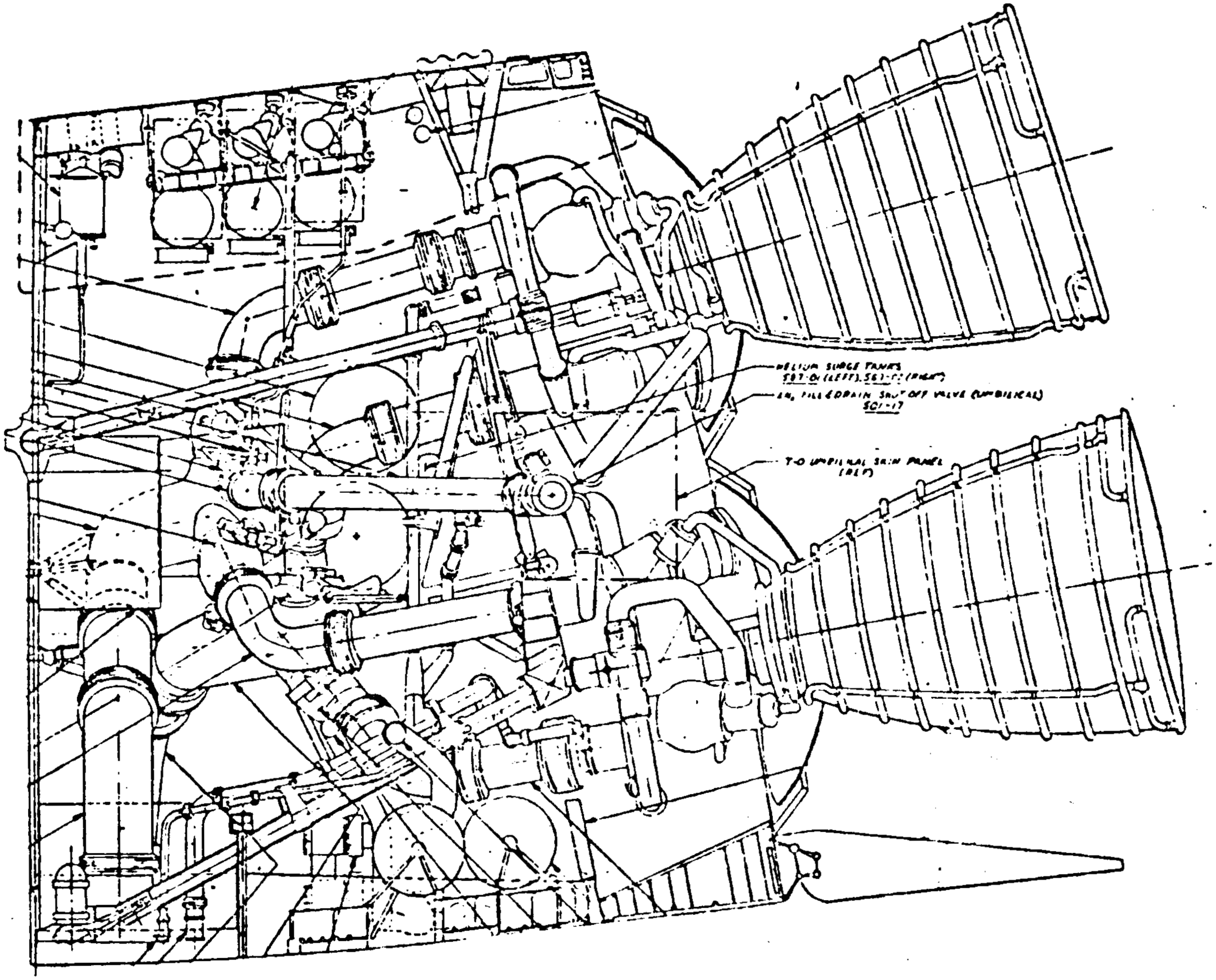
SPACE SHUTTLE ASSESSMENT

AFT FUSELAGE INBOARD PROFILE



ORBITER — HYDRAULIC LEAKAGE

TRANSPORT AIRCRAFT STATUS

- CURRENT WIDE-BODY AIRCRAFT PROBLEMS
  DC-10/B747/L-1011 HAVE
  MAJOR IMPROVEMENT
- DOUGLAS SERVICE REPORTS PROVIDE
  DATA FOR 3 MILLION AIRLINE FLIGHT HOURS
- OTHER MANUFACTURERS INDICATE SIMILAR SERVICE PROBLEMS
  TO DOUGLAS AIRCRAFT DC-10
- MILITARY SERVICE DATA NOT READILY AVAILABLE
- AIRCRAFT FAILURE DATA
  FAA SERVICE DIFFICULTY REPORTS ISSUED DAILY FOR ALL
  DOMESTIC AIRLINES
- LEAKAGE STILL A PROBLEM WITH BEST AVAILABLE
  TECHNOLOGY

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SPACE SHUTTLE ASSESSMENT

ORBITER — HYDRAULIC LEAKAGE

PROBLEM

- ORBITER MAY BE DAMAGED BY HYDRAULIC LEAKAGE
- SOAKED THERMAL TILES DEBOND DURING ASCENT
  VIBRATION + SOAKED TILE WILL FAIL BOND
  (VGES-135 JAN 1978)
- OIL ON APU WILL IGNITE AT 640°F
  APU EXHAUST PIPE
  INSULATION GAPS EXPOSE 1000°F SURFACE
  (R.I. PRESENTATION — JAN 1978)
- OIL DEGRADES HYDRAZINE LINE INSULATION CHARACTERISTICS
  IF WET AT THERMAL SENSOR — WILL OVERHEAT (>150°F)
  IF WET AWAY FROM THERMAL SENSOR — HYDRAZINE FREEZES
  — APU WILL NOT START
  (SEH-ITA-77-262 J. F. CLAWSON 11-22-77)

MCDONNELL DOUGLAS

SPACE SHUTTLE ASSESSMENT

AIR CARRIER

FLIGHT STANDARDS SERVICE DIFFICULTY REPORTS

DEPARTMENT OF TRANSPORTATION • UNITED STATES OF AMERICA

FLIGHT STDS SERVICE	RIS: FS 8070-2	Thursday, April 27, 1978

AIRFRAME

DATE	STATUS	CARRIER	ATA	AIRCRAFT TYPE	N	CONTROL NO
04-08-78	ORIG-CLOSED	AAL	2710	B747-123	9667	04278013

TEXT LAX. AFTER LANDING GEAR WAS RETRACTED ON TAKE-OFF, EXPERIENCED LOSS OF NR. 1 HYDRAULIC SYSTEM. LOSS STOPPED WHEN EDP PUT TO DEPRESSURIZE AND ADP TO OFF. USED ALTERNATE L/G AND FLAP EXTENSION PROCEDURES AND LANDED WITHOUT FURTHER INCIDENT. MAINTENANCE FOUND LATERAL FLIGHT CONTROL VALVE IN LEFT HAND WING CRACKED. REPLACED VALVE. SERVICED HYDRAULIC SYSTEM AND GROUND CHECKED.

SPECIFIC PART CAUSING PROBLEM

PART NAME	MFG PART NUMBER	PART CONDITION	PART/DEFECT LOCATION
VALVE	AV16E12153	CRACKED	L.H. WING

COMPONENT/APPLIANCE ABOVE PART INSTALLED ON

COMP/APPL NAME	MANUFACTURER	MFG MODEL/NUMBER	SERIAL NO	PART TT	PART TSO
FLIGHT CONTROL	ITT AEROSPACE			17534	

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ORBITER — HYDRAULIC LEAKAGE

ORBITER/TRANSPORT COMPARISON

- ORBITER DESIGN IS EQUIVALENT TO CURRENT TRANSPORTS, E.G., LINE SIZES, SUPPORT SPACING FITTINGS, ETC.
- ORBITER ENVIRONMENT MUCH MORE SEVERE AND PROBLEMS WILL OCCUR SOONER
- LEAKAGE MAKES ORBITER VULNERABLE TO:
  - THERMAL TILE SEPARATION
  - APU FIRES
  - HYDRAZINE LINE FREEZING
- ORBITER HAS NO COMPLETE HYDRAULIC SYSTEM GROUND TESTS AT FULL ENGINE POWER

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ORBITER — HYDRAULIC LEAKAGE

PROBABLE CAUSES OF LEAKAGE

- PRESSURE SURGES AND PUMP PRESSURE RIPPLE
  - RAPID VALVE CLOSURE
  - PUMP CASE DRAIN LINE
  - PUMP PRESSURE LINE
- VEHICLE VIBRATION
  - LINE ABRASION
  - ABRUPT LINE SIZE CHANGE AT REDUCER FITTINGS
  - LOOSENED FITTINGS
- LINES MISMATCHED AT INSTALLATION
- SERVICING MISHAPS
  - LARGE SPILLS

ORBITER — HYDRAULIC LEAKAGE

RECOMMENDATIONS

- SPECIAL INSPECTION OF SYSTEM INSTALLATION
  - — PROPER FIT OF LINES AT INSTALLATION
  - — LINE SUPPORT SPACING
  - — CLEARANCE
- LOCK WIRE TUBE FITTINGS
- EVALUATE HIGH-PRESSURE LINE SURGES AND PUMP PRESSURE RIPPLE
- CONTROL FLOW OF EXTERNAL LEAKAGE
  - — SEAL SKIN LAPPED JOINTS AND RIVETS
  - — DIRECT LEAK FLOW TO CONTAINERS, SUMPS, AND OVERBOARD DRAINS
  - — CONTROL SPILLS DURING SERVICING
    - CATCH SPILLS IN ABSORBENT PADS
    - RIGOROUS CLEANUP AFTER WORK
- PORTECT APU'S AND HYDRAZINE LINE INSULATION FROM HYDRAULIC LEAKAGE
  - — CONVOLUTED SCREEN AT INJECTOR WELL
- CONTAIN APU AND TURBINE PUMP

ORBITER — FREON LEAKAGE

PROBLEM

- LEAKAGE OF FREON INTO HYDRAULIC FLUID MAY LOSE FLUID IN TWO POWER SYSTEMS
- FREON/OIL HEAT EXCHANGER IS VULNERABLE TO WELD CRACKS
- PRESSURE DIFFERENCE LEAKS FREON INTO OIL
- FREON 21 AND BUNA N PACKINGS NOT COMPATIBLE
- SERVO CONTROL RESPONSE DEGRADED

RECOMMENDATIONS

- EVALUATE EFFECT OF VARIOUS FREON/OIL MIXTURES ON PACKINGS
- EVALUATE SERVO CONTROL RESPONSE
- PERIODIC ANALYSIS OF VEHICLE HYDRAULIC FLUID FOR FREON CONCENTRATION
- VIBRATION TEST FOR PRODUCTION ACCEPTANCE

ORBITER — LANDING GEAR BRAKE SYSTEM

PROBLEM

- LOSS OF BRAKE FLUID FROM:
  - BROKEN HOSES
  - EXTERNAL LEAKS AT BRAKE MANIFOLD
- MAY LOSE:
  - 50 PERCENT OF ALL BRAKING
  - 100 PERCENT BRAKING ON ONE MAIN GEAR
- STEERING AND STOPPING DISTANCE DEGRADED

RECOMMENDATIONS

- MINIMIZE BRAKE SYSTEM FAILURES
- COMPLETE ON-GOING ANALYSIS OF VEHICLE DECELERATION
- EVALUATE AUXILIARY BRAKING DEVICES

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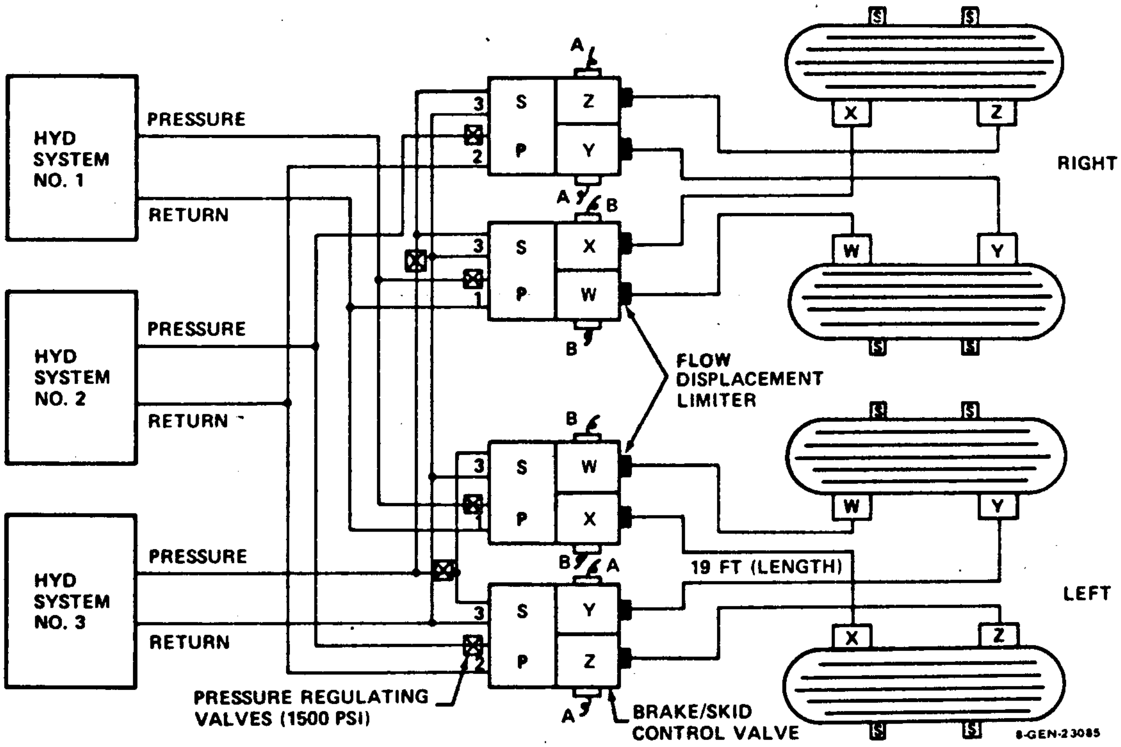
SPACE SHUTTLE ASSESSMENT

WHEEL BRAKE SUBSYSTEM



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SPACE SHUTTLE ASSESSMENT

ORBITER — BRAKE HOSE AND LINE DAMAGE

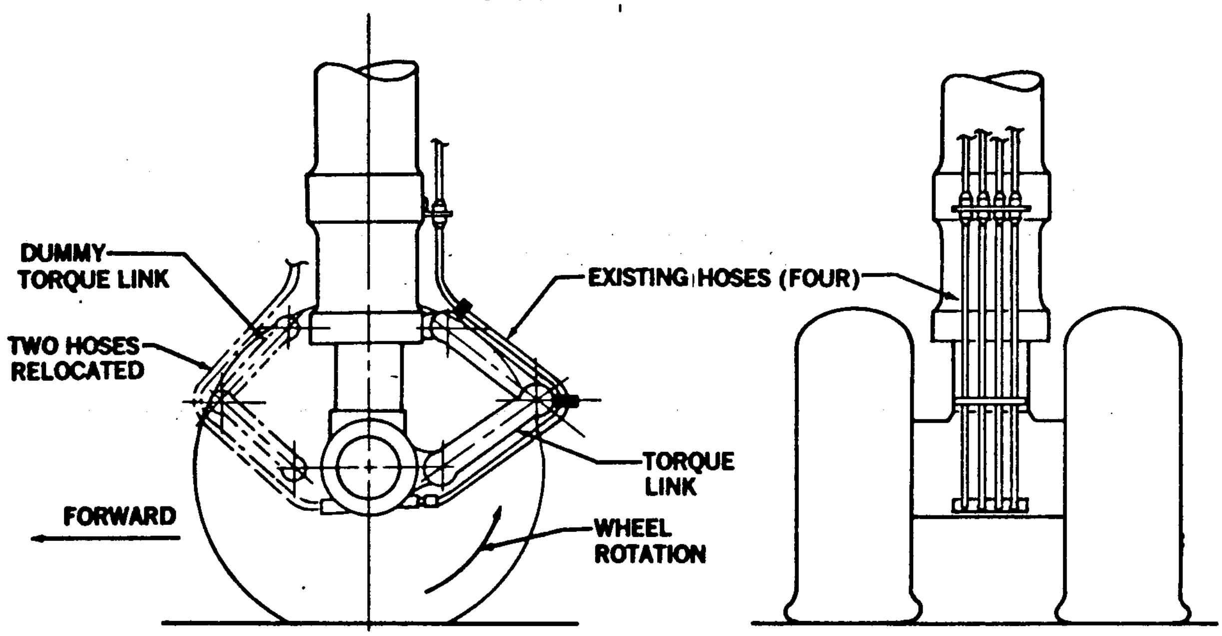
PROBLEM

- ALL BRAKES ON ONE LANDING GEAR MAY BE LOST TOGETHER
- TIRE BLOWOUT OR SEPARATED TREAD MAY SEVER FOUR BRAKE LINES AND HOSES

RECOMMENDATION

- SEPARATE SYSTEMS PER TRANSPORT AIRCRAFT STANDARDS
- LOCATE TWO BRAKE LINES EACH ON FORWARD AND AFT SIDE OF SHOCK STRUT (ONE OPTION)

MAIN LANDING GEAR HOSE LOCATION



ORBITER — BRAKE CONTROL VALVE LEAKAGE

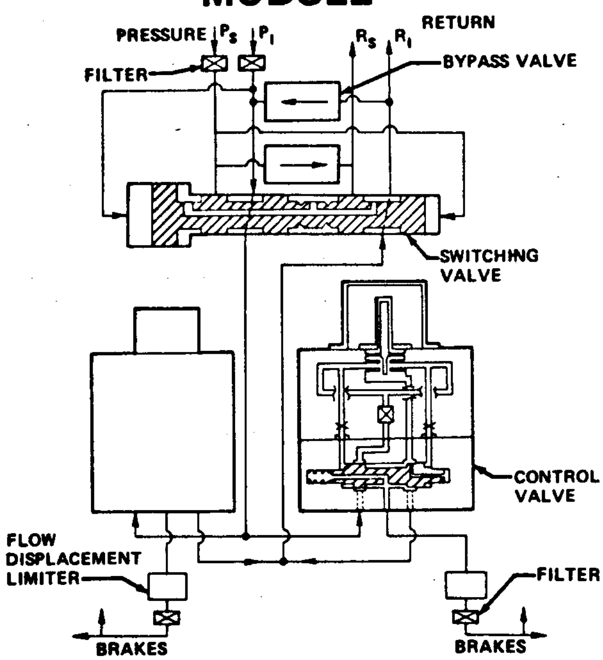
PROBLEM

- LOSE ONE-HALF OF BRAKING CAPACITY
- VALVE LEAKAGE CAN EXHAUST TWO POWER SYSTEMS
- VULNERABLE POINTS — BETWEEN SWITCHING VALVE AND FLOW DISPLACEMENT LIMITER:
  - PLUGS IN DRILLED PASSAGES
  - SINGLE EXTERNAL SEALS
  - CRACKED HOUSING
  - SWITCHING VALVE INTERNAL SEALS
  - THREADED PLUGS

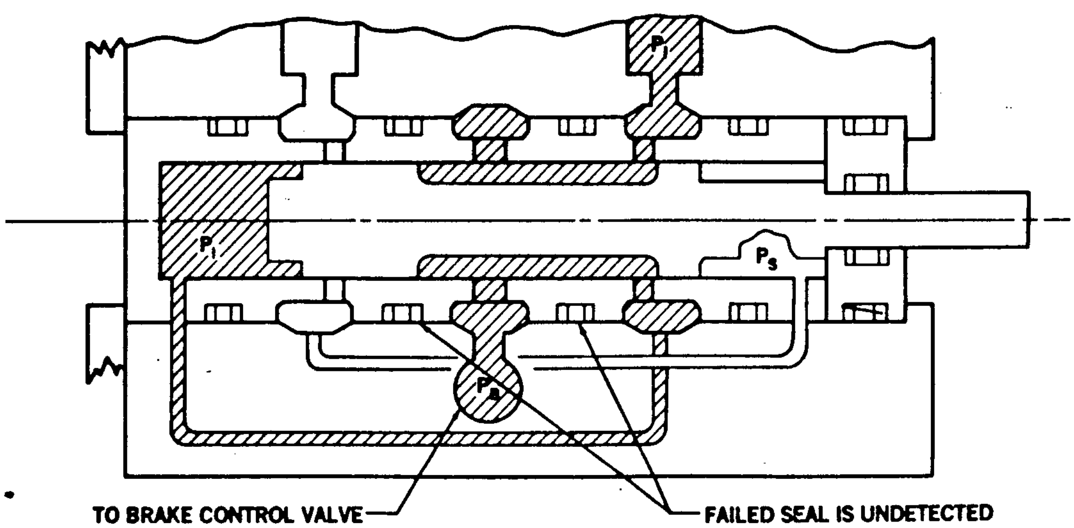
CORRECTIVE ACTION

- PROVIDE BACKUP LOCKS ON LEE PLUGS
- LOCKWIRE ALL EXTERNAL PLUGS AND CAPS
- PROVIDE INLET CHECK VALVES ON SUPPLY LINES
- REDUCE DIAMETRAL CLEARANCE ON SWITCHING VALVE SLEEVE

BRAKE VALVE MODULE



BRAKE/SKID CONTROL SWITCHING VALVE



SERVOCONTROL SYSTEMS ASSESSMENT

SERVO ACTUATOR SINGLE FAILURE POINTS

CRITICALITY CATEGORY I, IU FAILURE MODES

- JAMMED SPOOLS
- LOSS OF MECHANICAL FEEDBACK BIAS SPRING
- FAILURE OF INTERNAL STATIC/DYNAMIC SEALS
- FAILURE OF EXTERNAL STATIC/DYNAMIC SEALS
- ACTUATOR PISTON ROD PACKING GLANDS
- HYDRAULIC MOTOR BRAKE FAILURE
- ACTUATOR FRACTURE CONTROL PLAN

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SPACE SHUTTLE ASSESSMENT

JAMMED POWER VALVE/SWITCHING VALVE

SYSTEM

- POWER VALVE: SRB-TVC, SSME-TVC, ELEVONS, R/SB, BODY FLAP (TOTAL SFP 23)
- SWITCHING VALVE AND LOCK VALVE SRB-TVC (TOTAL SFP 8)

CAUSE

- EXCESSIVE CONTAMINATION EXCEEDING SHEARING CAPABILITY OF SPOOL.

RESULT

- SINGLE FAILURE POINT
- CRITICALITY "I" FAILURE MODE (IU FOR SWITCHING VALVE AND LOCK VALVE)
- LOSS OF CONTROL OF ACTUATOR/VEHICLE

RECOMMENDATION

- RECOMMENDED SOLUTION — INSTALL PROTECTIVE SCREENS AT ALL ACTUATOR/HYDRAULIC CONTROL MODULE INLET PORTS
  - PROTECTIVE SCREENS ARE INSTALLED ON DC-10 HYDRAULIC ACTUATORS/MODULES
- ALTERNATE SOLUTION — USE JAM PROOF VALVES

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SPACE SHUTTLE ASSESSMENT

INLET SCREENS

REMOVE LARGE PARTICLES THAT CAN ENTER A SYSTEM AND JAM VALVES

- HIGH VIBRATION ENVIRONMENT CAN PUT PARTICLES THAT WERE BUILT INTO SYSTEM AND NEVER FLUSHED OUT INTO CIRCULATION
- PARTICLES MAY ENTER SYSTEM WHEN COMPONENTS ARE OVERHAULED
- BY DIRECT INTRODUCTION WHEN LINES ARE OPENED FOR MAINTENANCE
- AS A RESULT OF THE FAILURE OF A COMPONENT

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SPACE SHUTTLE ASSESSMENT

LOSS OF ACTUATOR POSITION MECHANICAL FEEDBACK BIAS SPRING

SYSTEM

- SRB-TVC (TOTAL SFP 8)
- SSME-TVC (TOTAL SFP 12)

CAUSE

- LOSS OF BIAS SPRING
- BROKEN BIAS SPRING

RESULT

- SINGLE FAILURE POINT
- CRITICALITY "I" FAILURE MODE
- LOSS OF CONTROL OF TWO SERVO VALVES
- SERVO VALVE FORCE FIGHT OCCURS
- LOSS OF CONTROL OF ACTUATOR/VEHICLE

RECOMMENDATION

- PROVIDE POSITIVE CAGING OF BIAS SPRING
- NASA INDICATES REDESIGN IS TAKING PLACE

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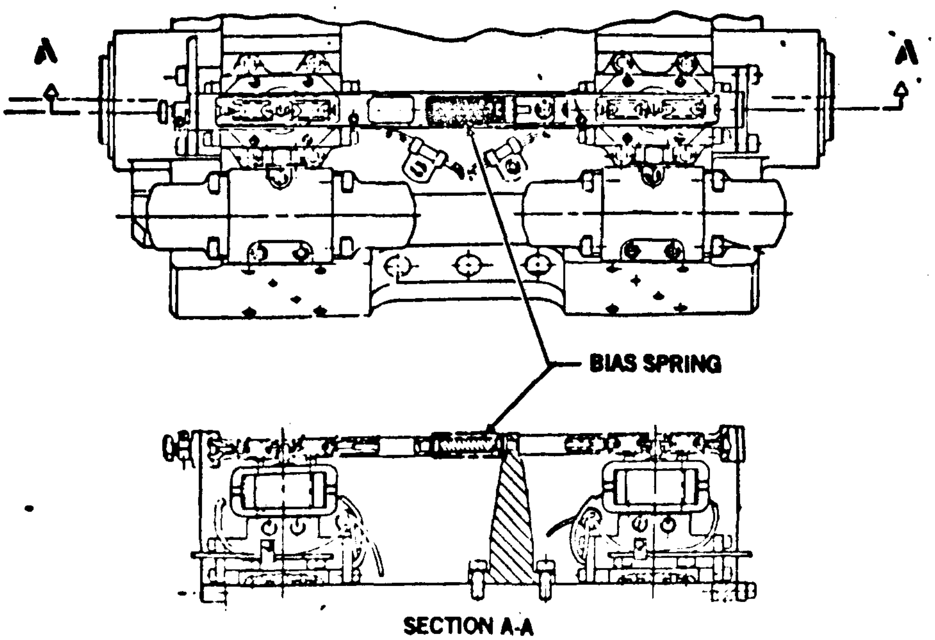
SPACE SHUTTLE ASSESSMENT

ACTUATOR POSITION MECHANICAL FEEDBACK BIAS SPRING INSTALLATION



FAILURE OF INTERNAL STATIC/DYNAMIC SEALS

SYSTEM

- SRB-TVC ACTUATOR PISTON HEAD SEAL (TOTAL SFP 4)

CAUSE

- DAMAGED SEAL DURING INSTALLATION
- DEFECTIVE SEAL
- DEFECTIVE SEAL GROOVE

RESULT OF SEAL FAILURE

- EXCESSIVE INTERNAL HYDRAULIC LEAKAGE PATH
- SINGLE FAILURE POINT
- CRITICALITY "I" FAILURE MODE
- LOSS OF CONTROL OF ACTUATOR/VEHICLE

HYDRAULIC FLUID INTERNAL LEAKAGE LIMITS

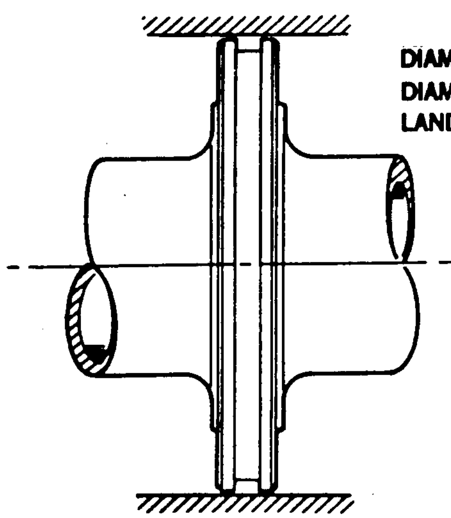
SOLID ROCKET BOOSTER

- MAXIMUM ALLOWABLE INTERNAL HYDRAULIC LEAKAGE 20.0 GPM
  (ESTABLISHED BY EXCESS HYDRAZINE ON-BOARD)

ORBITER

- MAXIMUM ALLOWABLE INTERNAL HYDRAULIC LEAKAGE 0.1 GPM
  (ESTABLISHED BY THE ORBITER CONFIGURATION CONTROL BOARD 12-3-76)

SRB-TVC ACTUATOR PISTON



DIAMETRICAL CLEARANCE = 0.007 INCH
DIAMETER = 7.306 INCH
LAND LENGTH = 0.4 INCH MINIMUM

TOTAL NUMBER OF SINGLE FAILURE POINTS: 4
FAILED SEAL LEAKAGE RATE GREATER THAN 35 GPM — NOT ACCEPTABLE

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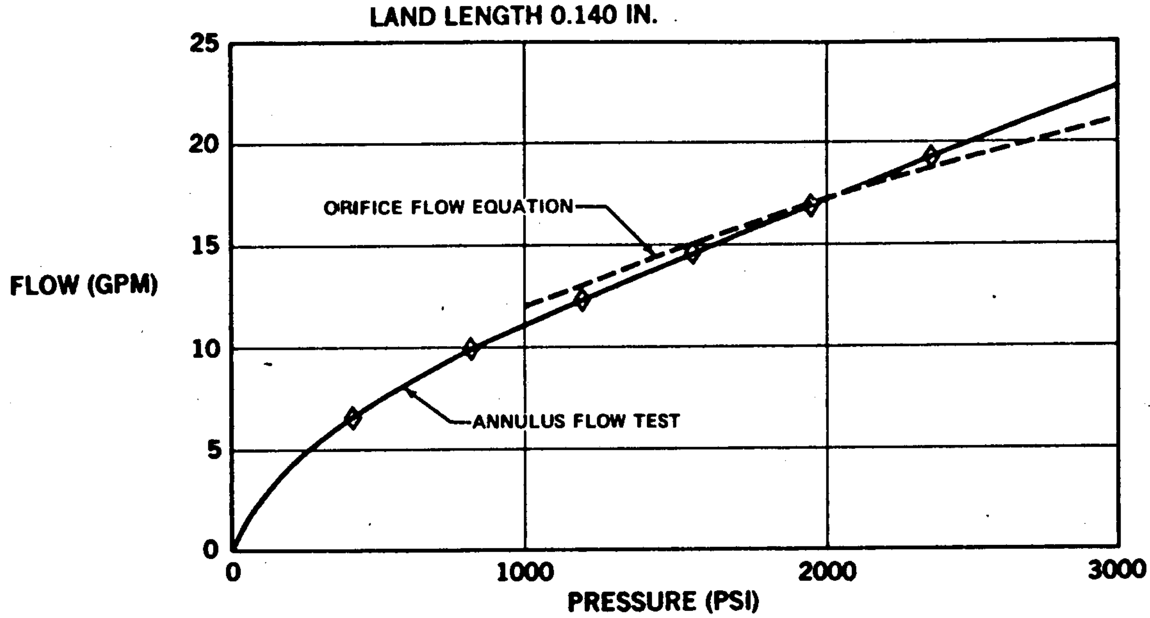
SPACE SHUTTLE ASSESSMENT

MSFC ANNULUS FLOW TESTS

TEMP 150°F
DIAMETRICAL CLEARANCE 0.005 IN.
DIAMETER 1.74 IN.
LAND LENGTH 0.140 IN.



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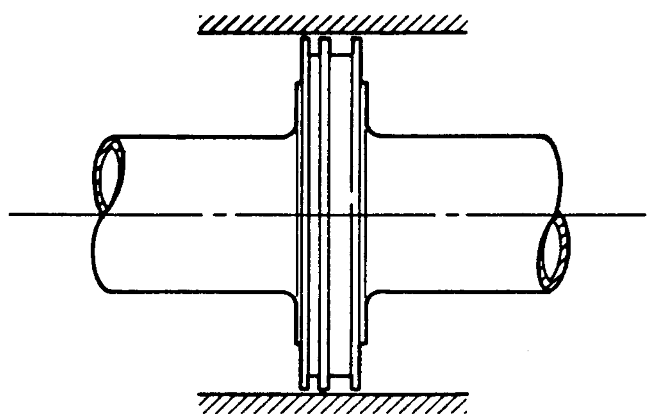
SPACE SHUTTLE ASSESSMENT

ELEVON ACTUATOR PISTON



PRIMARY SEAL

O-RING, BUNA N RUBBER WITH TEFLON CAP SEAL

FIX: PROVIDE A BARRIER SEAL

METALLIC RING — INNER RING 17-4 PH STAINLESS-STEEL
OUTER RING ALUMINUM BRONZE

FAILURE OF EXTERNAL STATIC/DYNAMIC SEALS

SYSTEM

- SSME-TVC FILTER INDICATOR, SERVO VALVES
- ELEVONS FILTER INDICATOR, SERVO VALVES
- R/SB FILTER INDICATOR, SERVO VALVES, SWITCHING VALVE MANIFOLD UNIONS
- SRB-TVC SWITCHING VALVE, TRANSIENT LOAD RELIEF VALVE

CAUSE

- SEAL DAMAGED DURING INSTALLATION
- DEFECTIVE SEAL
- DEFECTIVE SEAL GROOVE

RESULT OF SEAL FAILURE

- EXCESSIVE EXTERNAL LEAKAGE PATH
- SINGLE FAILURE POINT
- LOSS OF HYDRAULIC FLUID FROM MORE THAN ONE SYSTEM
- CRITICALITY CATEGORY I, IU FAILURE MODES
- LOSS OF CONTROL OF ACTUATOR/VEHICLE

HYDRAULIC FLUID EXTERNAL LEAKAGE LIMITS

SOLID ROCKET BOOSTER

MAXIMUM ALLOWABLE LOSS OF FLUID IS EQUIVALENT TO THE VOLUME OF FLUID IN TWO RESERVOIRS THAT COULD BE LOST DURING VEHICLE ASCENT

- MAXIMUM EXTERNAL LEAKAGE 2.0 GPM

ORBITER

MAXIMUM ALLOWABLE LOSS OF FLUID IS EQUIVALENT TO THE VOLUME OF FLUID IN ONE RESERVOIR THAT COULD BE LOST DURING VEHICLE ENTRY

- MAXIMUM EXTERNAL LEAKAGE 0.1 GPM
(ESTABLISHED BY THE ORBITER CONFIGURATION CONTROL BOARD 12-3-76)

EXTERNAL STATIC/DYNAMIC SEAL LEAKAGE RATES

COMPONENT	ΔP(PSI)	LEAKAGE RATES (GPM)	
• SRB-TVC TRANSIENT LOAD RELIEF VALVE SEAL NO. 1	2000	3.1	OPEN *
• SRB-TVC SWITCHING VALVE SEALS NO. 2 AND 3 (CRIT CAT. IU)	3000	23	NOT ACCEPTABLE
• SSME-TVC, R/SB, ELEVON SERVO VALVE FACE SEALS (PRESSURE RELIEF)	3000	<0.1	OPEN *
• SSME-TVC R/SB, ELEVON FILTER INDICATOR	3000	<0.1	OPEN *
• R/SB SWITCHING VALVE MANIFOLD UNION SEALS	3000		OVERSTRESS BOLTS, OPEN UP MOUNTING FACE, LOSE THREE HYDRAULIC SYSTEMS

* CORRECTIVE ACTION BEING TAKEN PER NASA

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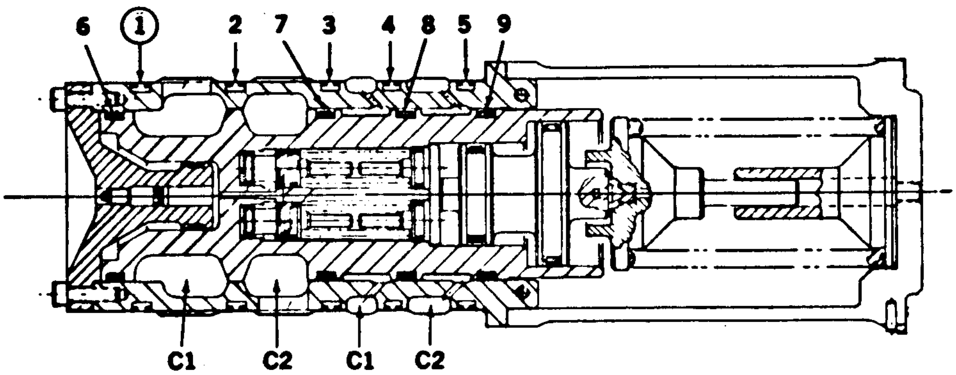
SPACE SHUTTLE ASSESSMENT

SRB TRANSIENT LOAD RELIEF VALVE



FAILED EXTERNAL SEAL NO. 1 LEAKAGE RATE: 3.1 GPM NOT ACCEPTABLE

TOTAL SINGLE FAILURE POINTS 4

FIX: PROVIDE A BARRIER SEAL. NASA INDICATES CORRECTIVE ACTION WILL BE TAKEN TO REDUCE LEAKAGE TO 0.1 GPM

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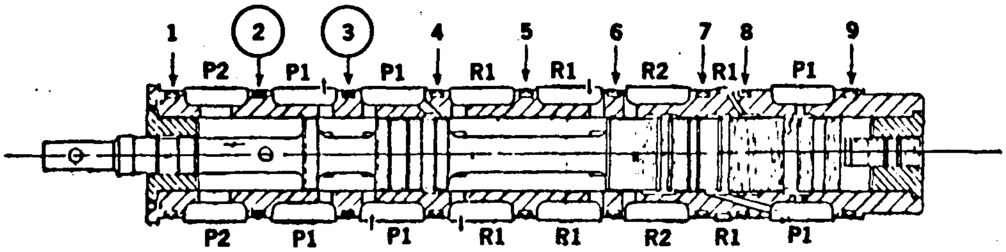
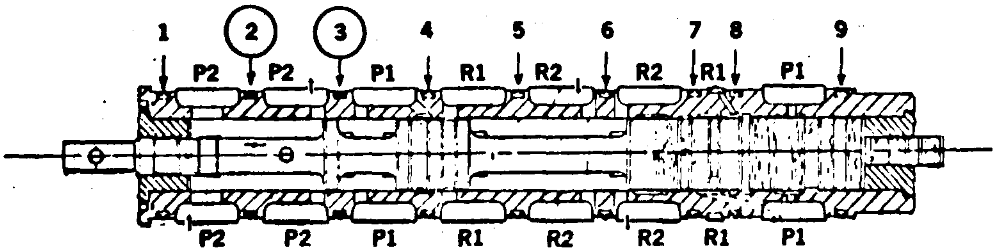
SPACE SHUTTLE ASSESSMENT

SRB-TVC SWITCHING VALVE



VALVE IN PRIMARY HYDRAULIC SUPPLY POSITION



VALVE IN STANDBY HYDRAULIC SUPPLY POSITION

FAILED EXTERNAL SEAL POTENTIAL LEAKAGE RATE

SEALS NO. 2 AND 3 - 23 GPM NOT ACCEPTABLE
CRITICALITY CATEGORY IU FAILURE MODE

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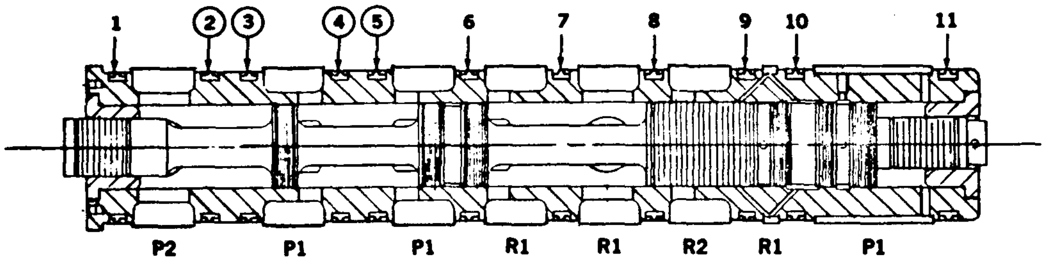
SPACE SHUTTLE ASSESSMENT

SWITCHING VALVE
RECOMMENDED ALTERNATE DESIGNS



SEALS: GREENE, TWEED "T" SEAL, BUNA N RUBBER WITH TEFLON BACKUP RINGS

FIX:

1. PROVIDE DUAL "T" SEALS AT SINGLE FAILURE POINT LOCATIONS WITH VENT THROUGH AN ORIFICE BACK TO RETURN TO PROVIDE A CONTROLLED LEAKAGE FLOW
2. PROVIDE CHECK VALVE IN EACH SUPPLY LINE TO PREVENT BACK FLOW OF HYDRAULIC FLUID

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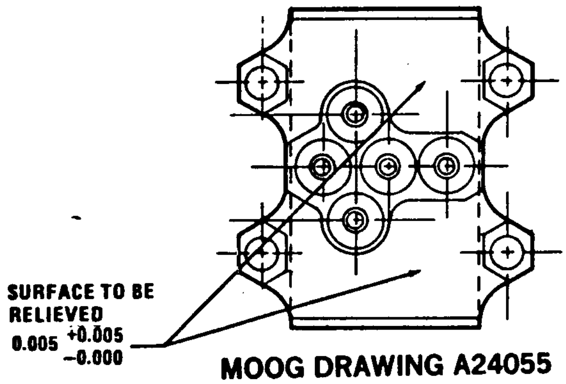
SERVO VALVE FACE SEAL LOAD RELIEF



MOOG DRAWING A24055
SERVO VALVE

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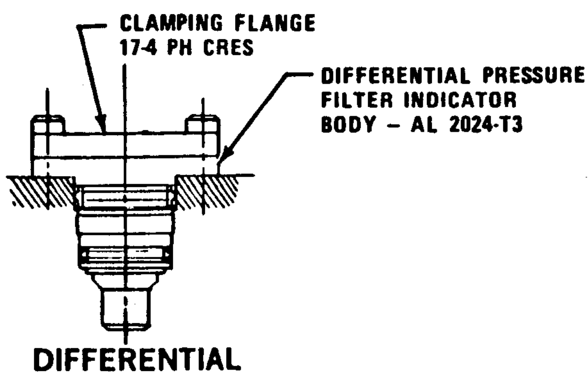
DIFFERENTIAL PRESSURE FILTER INDICATOR BARRIER SEAL



DIFFERENTIAL
PRESSURE
FILTER INDICATOR

FAILURE OF R/SB SWITCHING VALVE MANIFOLD UNION SEALS

	ASSUME PRESSURE IS ACTING ON TOTAL MANIFOLD FACE AREA	ASSUME PRESSURE IS ACTING ON 1/4 MANIFOLD FACE AREA	
MANIFOLD FACE AREA	50.2 $IN.^2$	12.55 $IN.^2$	12.55 $IN.^2$
OPERATING FLUID PRESSURE	3000 PSI	3000 PSI	3000 PSI
MANIFOLD FACE BOLT SIZE AND QUANTITY	3/8 DIA (8)	3/8 DIA (4)	3/8 DIA (2)
OPERATING LOAD PER BOLT	18,825 LB/BOLT	9413 LB/BOLT	18,825 LB/BOLT
BOLT YIELD ALLOWABLE LOAD AT 275°F	7594 LB	7594 LB	7594 LB
MARGIN OF SAFETY	-0.6	-0.19	-0.6

RECOMMENDATIONS

- SEAL FAILURE TEST SHOULD BE CONDUCTED TO VERIFY DESIGN.
- PROVIDE LOAD RELIEF TO PREVENT FORCE BUILDUP BETWEEN MANIFOLDS THAT COULD CAUSE BOLT FAILURE AND LOSS OF THREE HYDRAULIC SYSTEMS.

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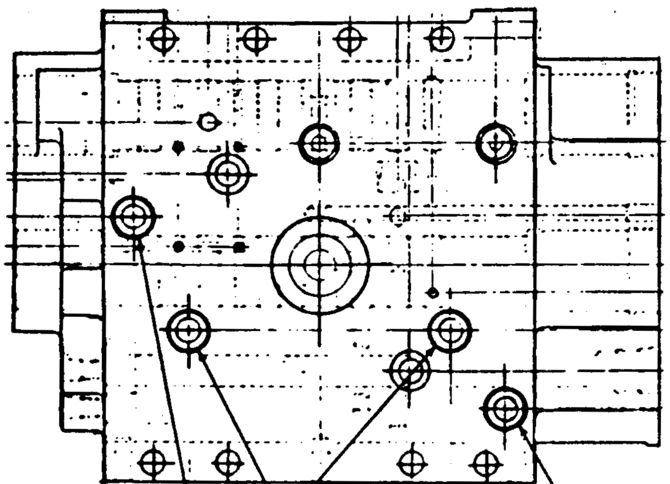
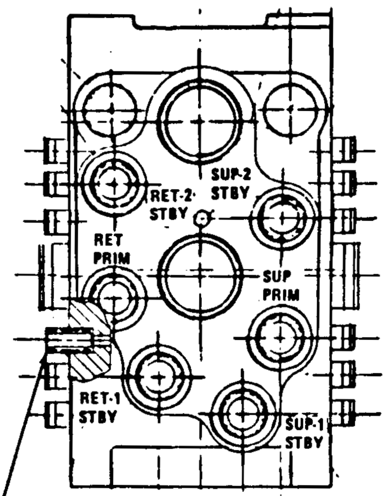
SPACE SHUTTLE ASSESSMENT

R/SB SWITCHING VALVE MANIFOLD AND UNIONS





SUMMARY
FAILURE OF EXTERNAL STATIC/DYNAMIC SEALS

COMPONENT	SRB-TVC	SSME TVC	ELEVONS	R/SB
• TRANSIENT LOAD RELIEF VALVE SEAL NO. 1	*	—	—	—
• FILTER DIFFERENTIAL PRESSURE INDICATOR	—	*	*	*
• SERVO VALVES	A	*	*	*
• UNIONS (MOOG DWG A23797)	C	C	C	✓(16)
• SWITCHING VALVE (CRIT IU) SEALS NO. 2 AND 3	✓ (8)	C	C	C

* CORRECTIVE ACTION TAKING PLACE
✓ CORRECTIVE ACTION NEEDS TO BE TAKEN
C CORRECTIVE ACTION TAKEN
A ACCEPTABLE
— COMPONENT NOT USED IN DESIGN

ACTUATOR PISTON ROD PACKING GLAND

- NO POSITIVE RESTRAINT OF PISTON ROD PACKING GLANDS IN SSME-TVC, ELEVONS AND SRB-TVC ACTUATORS. (TOTAL SSME SFP 12, ELEVON SFP 8, SRB SFP 8)
- PACKING GLANDS ARE RETAINED ONLY BY SHRINK FIT.
- PACKING GLANDS COULD UNSEAT AND A MASSIVE EXTERNAL LEAK OF ALL HYDRAULIC SYSTEMS OCCUR.
- DAC USES POSITIVE LOCKING OF PACKING GLANDS
- CORRECTIVE ACTION — PROVIDE POSITIVE LOCKING OF PACKING GLANDS.

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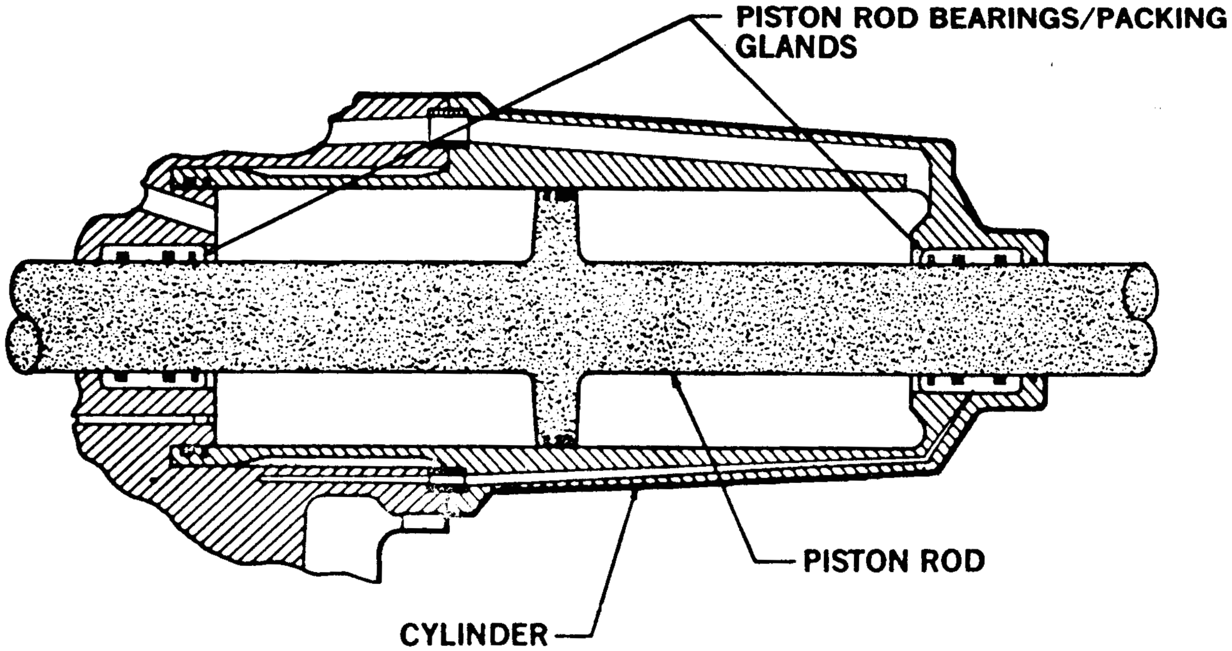
SPACE SHUTTLE ASSESSMENT

ELEVON ACTUATOR

CROSS-SECTIONAL VIEW



HYDRAULIC MOTOR BRAKE FAILS IN OFF POSITION

SYSTEM

- RUDDER
- SPEEDBRAKE
- BODY FLAP

CAUSE

- UNDETECTED HYDRAULIC BRAKE SPRING FAILURE
- UNDETECTED HYDRAULIC BRAKE PRESSURE PLATE FAILURE
- UNDETECTED HYDRAULIC BRAKE PISTON JAMMED
- FOLLOWED BY ONE HYDRAULIC SYSTEM FAILURE

RESULT

- THE REMAINING HYDRAULIC MOTORS WILL CAUSE THE FAILED MOTOR TO RUN IN REVERSE.
- THE UNIT IS UNABLE TO POSITION/DRIVE THE CONTROL SURFACE.
- THE SURFACE MAY BLOW BACK FROM ITS LAST COMMANDED POSITION.
- CRITICALITY CATEGORY IU

CORRECTIVE ACTION

- INSTALL REDUNDANT BRAKING DEVICE

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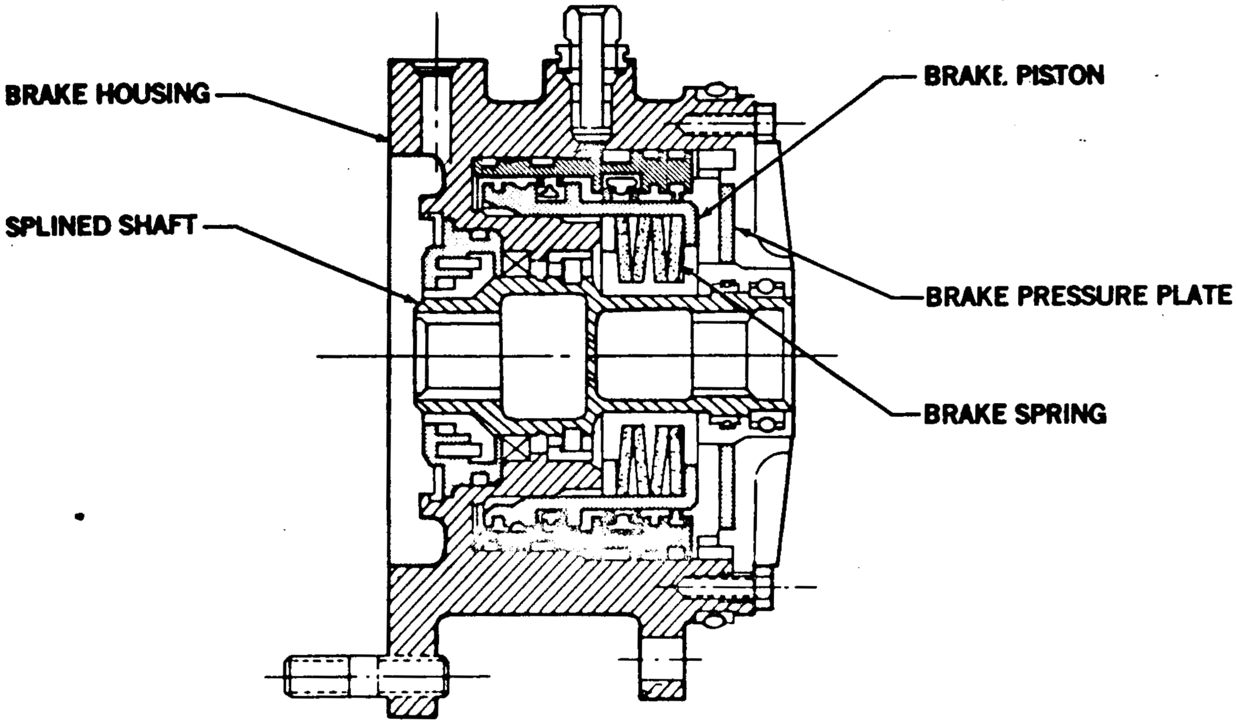
SPACE SHUTTLE ASSESSMENT

HYDRAULIC MOTOR BRAKE ASSEMBLY



ACTUATOR FRACTURE CONTROL PLAN

- FRACTURE CONTROL CRITERIA ENSURE THAT AN INITIAL FLAW OR CRACK WILL NOT GROW EXCESSIVELY AND CAUSE A FAST FRACTURE OF PART DURING THE MISSION TIME PERIOD
- FRACTURE CONTROL CRITERIA HAS BEEN APPLIED TO WING STRUCTURE AND TO ELEVON ACTUATOR ATTACH FITTINGS
- FRACTURE CONTROL ANALYSES OF ACTUATORS HAS BEEN DEFERRED
- ACTUATOR SPECIFICATIONS SHOULD REQUIRE FRACTURE CONTROL CRITERIA PER RI FRACTURE CONTROL PLAN SD73-SH-0082A SINCE ACTUATORS ARE FLIGHT CRITICAL ITEMS.
- ANALYSES SHOULD BE ACCOMPLISHED AS SOON AS POSSIBLE TO MINIMIZE IMPACT OF TESTING AND CHANGES TO SHUTTLE PROGRAM

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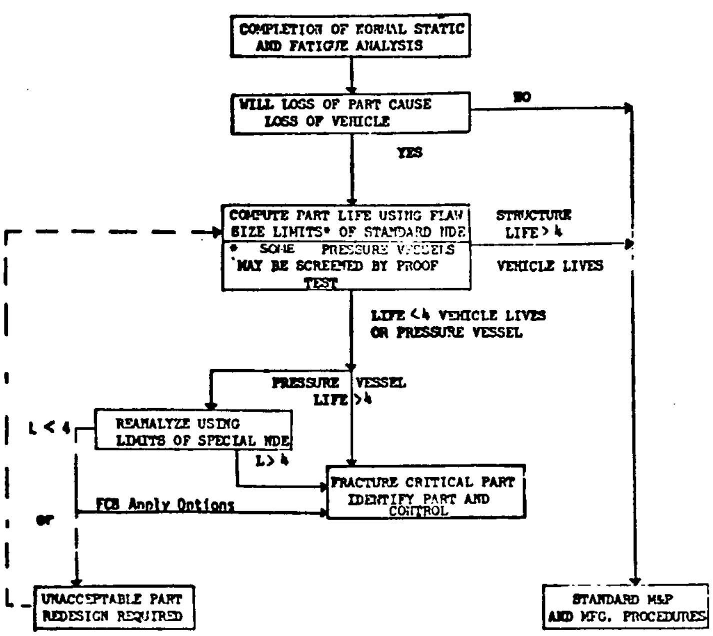
SPACE SHUTTLE ASSESSMENT

RI DOCUMENT SD73-SH-0082A PG. 4 FRACTURE CONTROL PLAN



LEGEND: L = LIFE
NDE = NON DESTRUCTIVE EVALUATION

FRACTURE CRITICAL PART SELECTION LOGIC

FIGURE 1

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SPACE SHUTTLE ASSESSMENT

SUMMARY OF CORRECTED SINGLE FAILURE POINT ITEMS

THE FOLLOWING SINGLE FAILURE POINT ITEMS HAVE BEEN OR ARE BEING CORRECTED

- SRB-TVC
  1. CAGING OF ACTUATOR POSITION MECHANICAL FEEDBACK BIAS SPRING
  2. TRANSIENT LOAD RELIEF VALVE EXTERNAL SEAL
- SSME-TVC
  1. CAGING OF ACTUATOR POSITION MECHANICAL FEEDBACK BIAS SPRING
  2. SERVO VALVE FACE SEAL LOAD RELIEF
  3. FILTER DIFFERENTIAL PRESSURE INDICATOR SEAL BARRIER
- RUDDER/SPEEDBRAKE
  1. SERVO VALVE FACE SEAL LOAD RELIEF
  2. FILTER DIFFERENTIAL PRESSURE INDICATOR SEAL BARRIER
- ELEVONS
  1. SERVO VALVE FACE SEAL LOAD RELIEF
  2. FILTER DIFFERENTIAL PRESSURE INDICATOR SEAL BARRIER

MCDONNELL DOUGLAS

SPACE SHUTTLE ASSESSMENT

SUMMARY OF OPEN SINGLE FAILURE POINT ITEMS

THE FOLLOWING MODULES DO NOT FULLY COMPLY WITH THE FORTRESS CONCEPT. A FEW SINGLE FAILURE POINTS CRITICALITY CATEGORY I AREAS STILL EXIST

- SRB-TVC
  1. ACTUATOR PISTON HEAD SEAL FAILURE
  2. SWITCHING VALVE CRITICALITY IU SEAL FAILURE
  3. LOSS OF PISTON ROD PACKING GLAND
  4. EXPEDITE FRACTURE CONTROL ANALYSIS
- RUDDER/SPEEDBRAKE
  1. SWITCHING VALVE MANIFOLD UNION SEAL FAILURE
  2. HYDRAULIC MOTOR BRAKE FAILURE
- ELEVON
  1. LOSS OF PISTON ROD PACKING GLAND
  2. EXPEDITE FRACTURE CONTROL ANALYSIS
- SSME-TVC
  1. LOSS OF PISTON ROD PACKING GLAND
  2. EXPEDITE FRACTURE CONTROL ANALYSIS
- BODY FLAP
  1. HYDRAULIC MOTOR BRAKE FAILURE
- ALL HYDRAULIC MODULE PACKAGES
  1. INSTALL INLET SCREENS

HYDRAULIC SYSTEM ARCHITECTURE ASSESSMENT

SOLID ROCKET BOOSTER TVC ACTUATION ARCHITECTURE ASSESSMENT

SRB TVC ASSESSMENT

HORSEPOWER REQUIREMENTS

NORMAL REQUIRED GIMBAL RATE 5 DEGREES/SECOND

- SUFFICIENT HORSEPOWER AVAILABLE WITH
  - PRESENT ACTUATOR SIZING
  - EXISTING PRESSURE DROP THROUGH ACTUATOR
  - TWO APU-DRIVEN HYDRAULIC POWER SYSTEMS

STANDBY REQUIRED GIMBAL RATE 3 DEGREES/SECOND

- SUFFICIENT HORSEPOWER AVAILABLE WITH
  - APU OVERSPEED 113 PERCENT
  - NORMAL PUMP VOLUMETRIC EFFICIENCY
  - SYSTEM LEAKAGE NOT EXCESSIVE

ELIMINATE APU OVERSPEED OPERATION

- PROVIDING STABLE CONTROL ACHIEVED WITH REDUCED GIMBAL RATE
  - SIMPLIFIES SYSTEM

SRB TVC ASSESSMENT SUMMARY

SRB/TVC ACTUATOR SYSTEM ARCHITECTURE CONSISTING OF

- TWO REDUNDANT HYDRAULIC SYSTEMS
- SINGLE TYPE SERVO ACTUATOR PACKAGES INCORPORATING SWITCHING VALVES

ACCEPTABLE PROVIDING

- REVISIONS IDENTIFIED BY THIS ASSESSMENT TEAM ARE INCORPORATED
- ON-PAD PRELAUNCH TESTS ARE USED TO DISCLOSE ABNORMAL LEAKAGE AND PUMP OUTPUT

ORBITER HYDRAULIC SYSTEM ARCHITECTURE ASSESSMENT

ORBITER ASSESSMENT

AREAS OF STUDY

HYDRAULIC POWER

SUPPLY
DISTRIBUTION
HORSEPOWER

ACTUATION

SSME TVC
ME CONTROLS
BODY FLAP (VALVES AND MOTORS)
RUDDER/SPEED BRAKE (POWER DRIVE UNIT)
ELEVON

ORBITER ASSESSMENT

HYDRAULIC POWER

SUPPLY

- THREE REDUNDANT HYDRAULIC SYSTEMS
- ONE HYDRAULIC PUMP/SYSTEM
- EACH DRIVEN BY IDENTICAL APU SUBSYSTEMS

REDUNDANCY EVALUATION

- PREFER TWO PUMPS/SYSTEM — NOT COMPATIBLE WITH LOADING
- PREFER DIFFERENT TYPES OF DRIVING SUBSYSTEMS — NOT REASONABLY ATTAINABLE

RECOMMENDATION

- EXISTING ARCHITECTURE ACCEPTABLE FOR OPERATION SPACE SHUTTLE ORBITER

ORBITER ASSESSMENT

HYDRAULIC POWER

DISTRIBUTION

- PRIMARY FLIGHT CONTROLS
  - SSME-TVC ACTUATION
  - ME CONTROLS
  - B/F ACTUATION
  - R/SB ACTUATION
  - ELEVON ACTUATION
- UTILITY SYSTEM
  - LANDING GEAR ACTUATION
  - BRAKES
  - NOSE WHEEL STEERING
  - ET UMBILICAL RETRACTION
- FLIGHT CONTROLS DICTATE BASIC ARCHITECTURE
- THREE REDUNDANT HYDRAULIC SYSTEMS

REQUIREMENTS	COMMERCIAL	ORBITER
• POSITIVE STANDBY POWER	YES	NO
• INDEPENDENT SYSTEMS	YES	NO
• SINGLE SYSTEM OPERATION	YES	NO

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ORBITER ASSESSMENT

HYDRAULIC POWER

DISTRIBUTION (CONTINUED)

- NUMEROUS SINGLE FAILURE POINTS DOWNSTREAM OF SWITCHING VALVES CAN RESULT IN LOSS OF ORBITER
  - SEALS
  - FRACTURED HOUSINGS
  - BOLT FAILURES
- FLIGHT CONTROL ACTUATOR PACKAGES
  - INCORPORATE SWITCHING VALVES
  - AUTOMATICALLY SELECT ONE SYSTEM AFTER ANOTHER WHEN FAILURE OCCURS
- RECOMMENDATION
  - ELIMINATE SINGLE FAILURE POINTS

MCDONNELL DOUGLAS

SPACE SHUTTLE ASSESSMENT

ORBITER ASSESSMENT

HORSEPOWER

REQUIREMENT

- SAFE FLIGHT WITH ANY ONE SYSTEM OPERATIVE

DEFICIENCY

- ASCENT PHASE OF FLIGHT
  - TWO SYSTEMS REQUIRED
  - DURATION 13.44 MINUTES
- APPROACH AND LANDING
  - TWO SYSTEMS REQUIRED

RECOMMENDATION

- IMPROVE DESIGN OF FLIGHT CONTROL ACTUATORS

MCDONNELL DOUGLAS

SPACE SHUTTLE ASSESSMENT

ORBITER ASSESSMENT

SPACE SHUTTLE MAIN ENGINE THRUST VECTOR CONTROL ACTUATION

- SINGLE TYPE ACTUATOR PACKAGES
  - SWITCHING VALVES
  - ONLY TWO SYSTEMS SUPPLY EACH ACTUATOR PACKAGE
  - OPERATE FOR 13.44 MINUTES AFTER LAUNCH

ANALYSIS BASED ON DC-10 ACTUATOR RELIABILITY RECORDS INDICATE ORBITER SSME TVC ACTUATOR PACKAGE EXISTING DESIGN IS MARGINALLY ACCEPTABLE

RECOMMENDATION

- IMPLEMENT "FORTRESS" PROGRAM
  - FRACTURE CONTROL PLAN
  - OPTIMUM DESIGN
  - SUPERIOR QUALITY CONTROL

MCDONNELL DOUGLAS

SPACE SHUTTLE ASSESSMENT

ORBITER ASSESSMENT

MAIN ENGINE FUEL CONTROL

- DIFFERENT HYDRAULIC SYSTEM TO EACH ENGINE
- MAIN ENGINE HYDRAULIC SYSTEM ISOLATION VALVES
- EXISTING ARCHITECTURE ACCEPTABLE FOR OPERATIONAL SPACE SHUTTLE ORBITER

MCDONNELL DOUGLAS

SPACE SHUTTLE ASSESSMENT

ORBITER ASSESSMENT

BODY FLAP HYDRAULIC ACTUATION

- HYDRAULIC SYSTEMS COMPLETELY SEPARATED
  - NO SINGLE FAILURE CAN CAUSE LOSS OF MORE THAN ONE HYDRAULIC SYSTEM
- HYDRAULIC BRAKE FAILURE OR VALVE JAM ONLY SFP
  - DETAIL DESIGN PROBLEMS
- BODY FLAP ARCHITECTURE IS ACCEPTABLE FOR OPERATIONAL SPACE SHUTTLE ORBITER

ORBITER ASSESSMENT

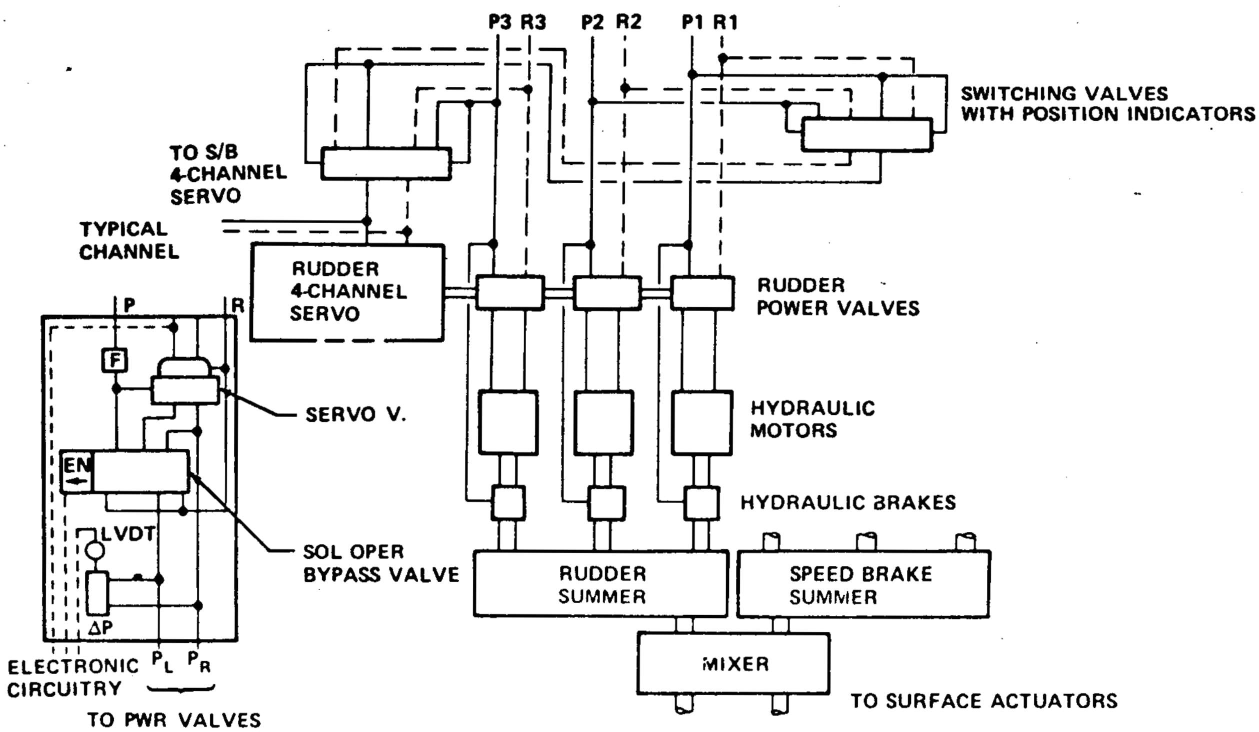
RUDDER/SPEED BRAKE HYDRAULIC ACTUATION

EXISTING DESIGN

- SINGLE FAILURE DOWNSTREAM OF SWITCHING VALVES CAN CAUSE LOSS OF ORBITER
- SWITCHING VALVES AUTOMATICALLY SELECT ONE SYSTEM AFTER ANOTHER FOR FOUR-CHANNEL SERVOS
  - EACH CHANNEL INCORPORATES THREE CRITICAL COMPONENTS
  - 24 CRITICAL COMPONENTS TOTAL IN R/SB SYSTEM
    - SEAL FAILURES
    - FRACTURED HOUSINGS
    - OVERTORQUED, UNDERTORQUED OR FAILED BOLTS

RUDDER/SPEED BRAKE

EXISTING DESIGN



ORBITER ASSESSMENT

RUDDER/SPEED BRAKE ACTUATION

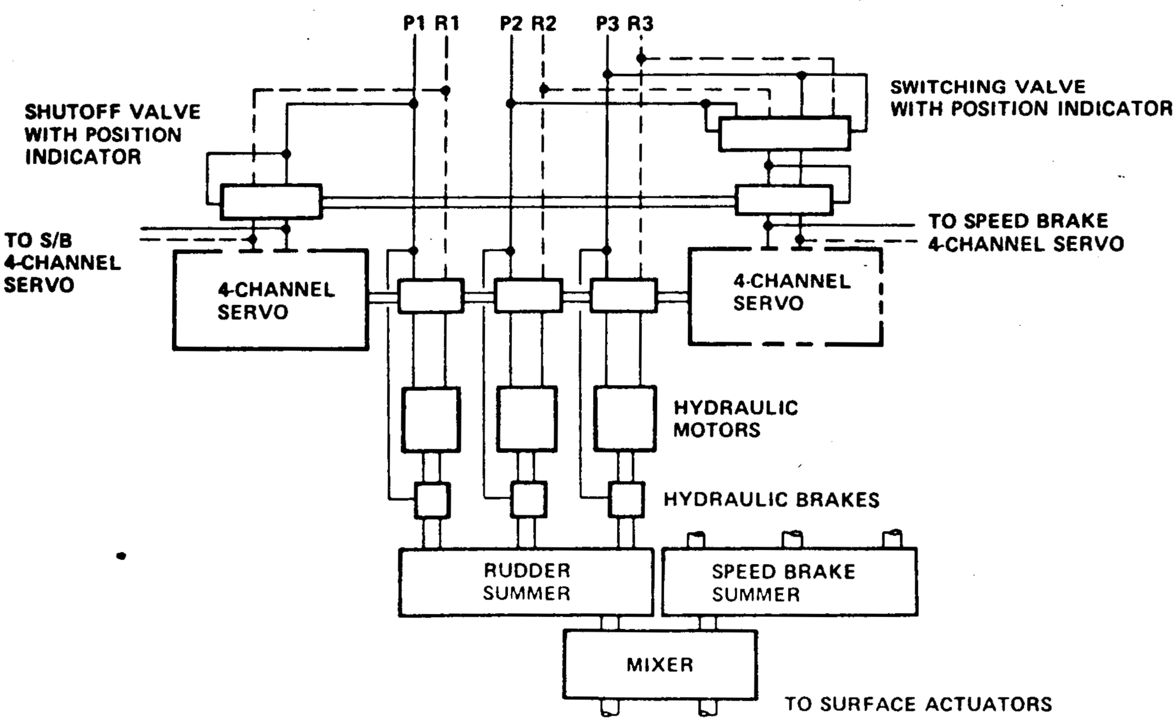
ROCKWELL PROPOSED DESIGN

- ELIMINATED SFP'S IN R/SB HYDRAULIC PDU 4-CHANNEL SERVOS
- ADDED TWO LINKED SHUTOFF VALVES WITH POSITION INDICATORS
- ADDED TWO FOUR-CHANNEL SERVOS
    - AVIONIC IMPACT
        - ADDED WIRING TO PDU
        - MODIFIED ASA HARDWARE
    - INCREASED QUIESCENT HYDRAULIC FLOW
    - INCREASED SIZE AND WEIGHT OF PDU
    - INCREASED COST OF PDU

McDONNELL DOUGLAS
SPACE SHUTTLE ASSESSMENT

RUDDER/SPEED BRAKE

ROCKWELL TANDEM OPTION



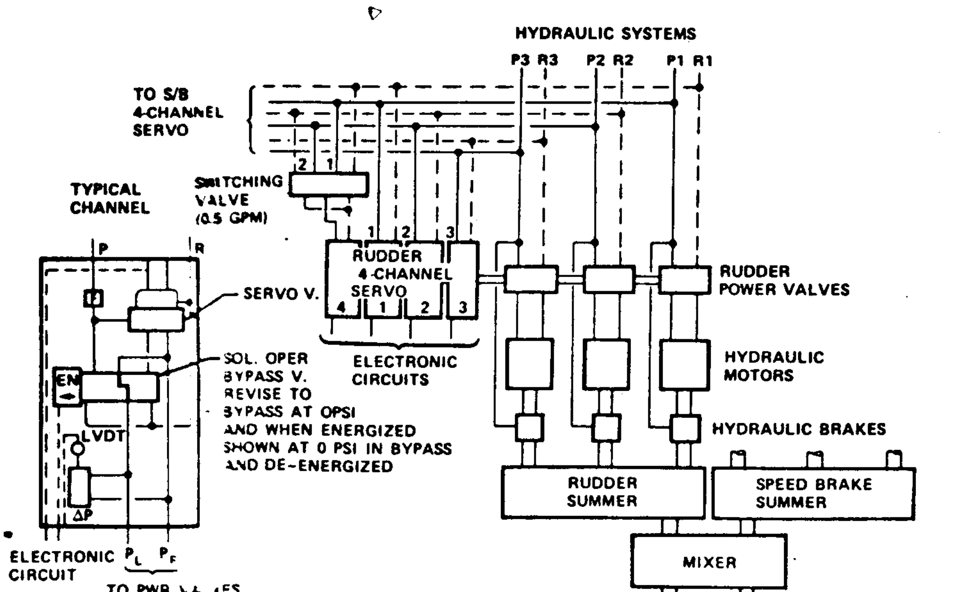
ORBITER ASSESSMENT
RUDDER/SPEED BRAKE ACTUATION

MDC PROPOSED DESIGN

- ELIMINATES ALL SFP'S IN R/SB HYDRAULIC PDU 4 CHANNEL SERVOS
  - 24 COMPONENTS NO LONGER CRITICALITY CATEGORY I HAZARD ITEMS
- ELIMINATES TWO EXISTING LARGE SWITCHING VALVES
- REROUTES SYSTEMS WITHIN ACTUATOR PACKAGE
  - SUPPLIES SEPARATE POWER TO EACH CHANNEL OF EXISTING FOUR-CHANNEL SERVOS
  - ADDS SMALL (0.5-GPM) SWITCHING VALVE
  - PRESSURE DIFFERENCES AMONG SYSTEMS IS SMALL
  - EXISTING ELECTRONIC CIRCUITRY IS TOLERANT OF DIFFERENCES
- NO CHANGE IN AVIONICS
  - NO CHANGE IN ELECTRONIC CIRCUITRY
  - NO CHANGE IN ASA HARDWARE
- RESULTS IN SMALLER PDU PACKAGE
- REDUCES ORBITER TOTAL WEIGHT ABOUT 20 POUNDS
- COST ESTIMATE (ROM) $2M FOR 4 SHIP SETS AND FCHL
- SCHEDULE IMPACT 15 MONTHS

RUDDER/SPEED BRAKE

MDC PROPOSED DESIGN



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SPACE SHUTTLE ASSESSMENT

ORBITER ASSESSMENT

RUDDER/SPEED BRAKE ACTUATION

- RECOMMEND GEAR RATIO REVISION
  - PROVIDE REQUIRED DESIGN HINGE MOMENT ONLY
  - REDUCES STRUCTURAL LOAD REQUIREMENTS
  - REDUCES FLOW REQUIREMENTS
    - RESULTS IN INCREASED AVAILABLE SURFACE RATE WHICH NOW IS
      - MARGINAL FOR COMBINED FLIGHT CONTROL ACTUATION DURING APPROACH AND LANDING
      - CRITICAL FOR SINGLE HYDRAULIC SYSTEM OPERATION

MCDONNELL DOUGLAS

SPACE SHUTTLE ASSESSMENT

ORBITER ASSESSMENT

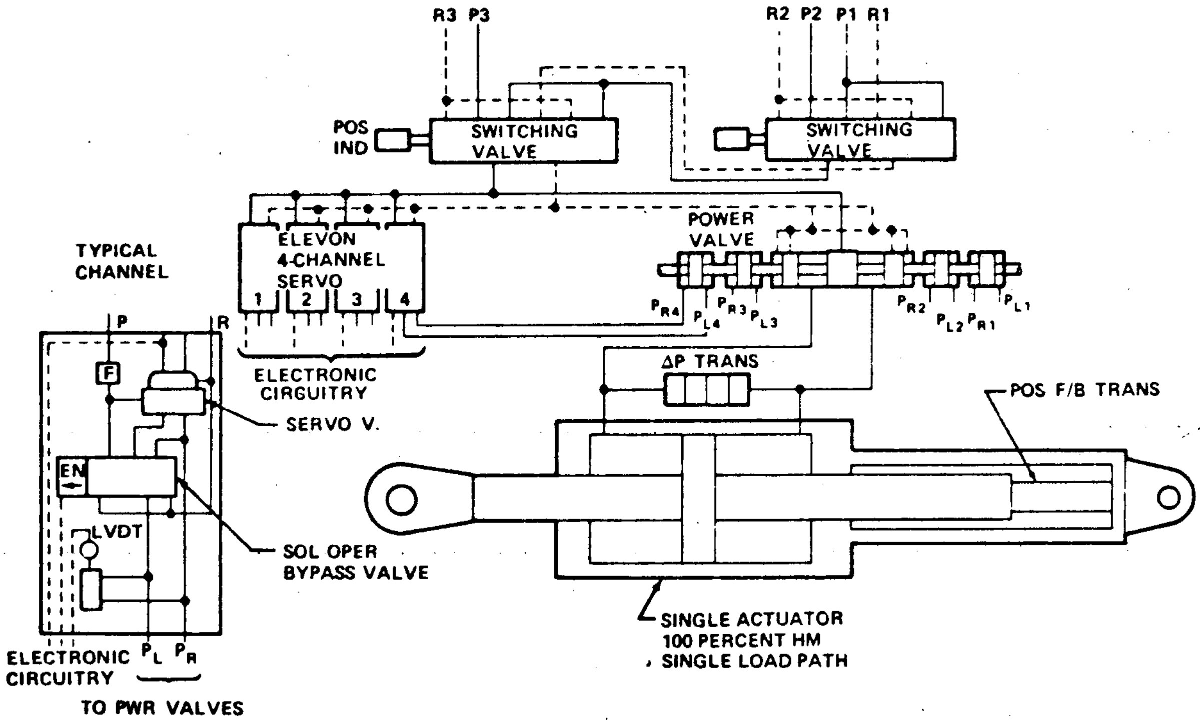
ELEVON ACTUATION

- EXISTING DESIGN
  - SINGLE FAILURE POINTS TOO NUMEROUS
    - 4 SINGLE TYPE SERVO ACTUATORS
    - FOUR-CHANNEL SERVO — 12 CRITICAL COMPONENTS
    - FOUR DYNAMIC FEEDBACK SENSORS
    - TWO MANIFOLDS
    - ACTUATOR
  - EACH ACTUATOR INCORPORATES TWO SWITCHING VALVES
    - AUTOMATICALLY SELECTS ONE SYSTEM AFTER ANOTHER
    - LIMITS REDUNDANCY AND RELIABILITY ACHIEVABLE
  - CRITICALITY CATEGORY I HAZARD ITEM
    - PRESSURE VESSEL
    - STRUCTURAL MEMBER
  - MARGINAL FLOW AVAILABLE FOR NORMAL THREE-SYSTEM OPERATION
    - SIZED TO DELIVER 100 PERCENT DESIGN HM
    - DIFFERENT HYDRAULIC SYSTEMS SUPPLY EACH ACTUATOR
      - DISTRIBUTES HORSEPOWER REQUIREMENTS
      - INCREASES FLOW REQUIREMENTS
  - FLOW DEFICIENT FOR SINGLE SYSTEM OPERATION FOR LANDING

MCDONNELL DOUGLAS

ELEVON ACTUATOR

EXISTING DESIGN



MCDONNELL DOUGLAS

OBITER ASSESSMENT

ELEVON ACTUATION

- EXISTING SYSTEM VULNERABLE TO FAILURE IN 10-YEAR OPERATIONAL LIFE
  - ANALYSIS BASED ON COMMERCIAL AIRCRAFT SERVICE RECORDS
  - AVERAGE IN-FLIGHT TIME ABOUT SAME AS ORBITER
  - NO ON-ORBIT TIME FOR COMMERCIAL AIRCRAFT
- ANALYSIS INDICATES LOW PROBABILITY OF ACHIEVING "NO FAILURES"

RECOMMENDATION

- INSTALL TANDEM ACTUATORS INCORPORATING
  - "FORTRESS" PROGRAM
    - FRACTURE CONTROL PLAN OR DUAL LOAD PATH
    - RIP STOP CONSTRUCTION
    - OPTIMUM DESIGN
    - SUPERIOR QUALITY CONTROL

ORBITER ASSESSMENT

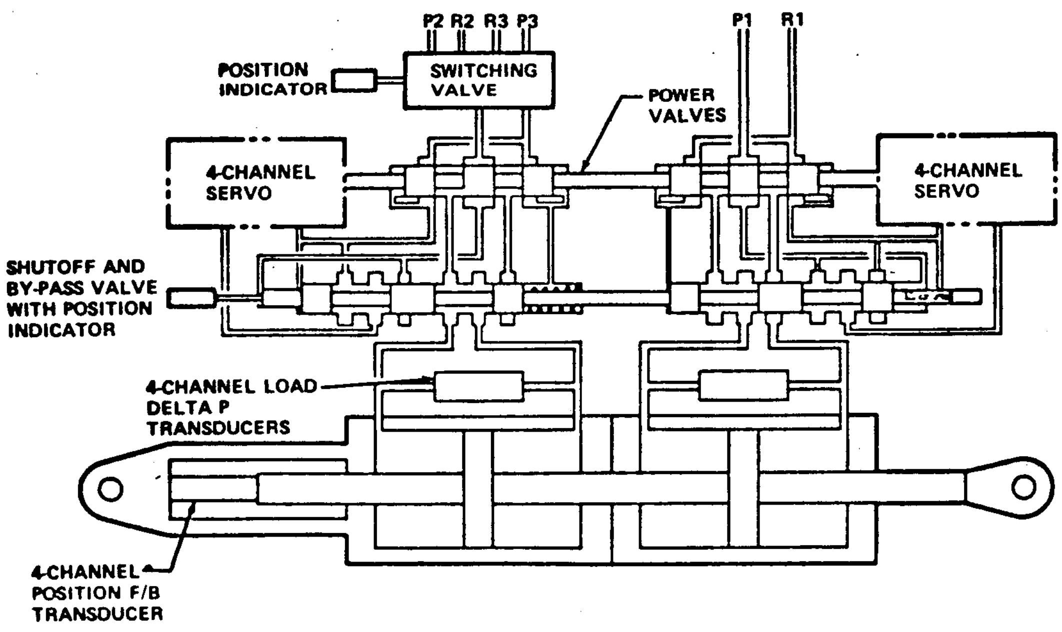
ELEVON ACTUATION

ROCKWELL PROPOSED TANDEM ACTUATOR DESIGN

- ELIMINATES ALL SFP'S AS A PRESSURE VESSEL IN ACTUATOR PACKAGES
- EACH HALF OF ACTUATOR PRODUCES 100 PERCENT DESIGN HINGE MOMENT
- ADDED TWO LINKED SHUTOFF AND BYPASS VALVES
- ADDED FOUR-CHANNEL SERVO FOR EACH ELEVON PACKAGE
    - ADDITIONAL ELECTRONIC CIRCUITRY
    - MODIFIES ASA HARDWARE
- 7.5-PERCENT INCREASE IN HYDRAULIC POWER REQUIRED
- ACTUATOR LENGTH INCREASE
    - WING STRUCTURE MODIFICATIONS REQUIRED
    - NEW ACTUATOR SUPPORT FITTINGS REQUIRED

TANDEM ELEVON ACTUATOR

ROCKWELL PROPOSED DESIGN



ORBITER ASSESSMENT

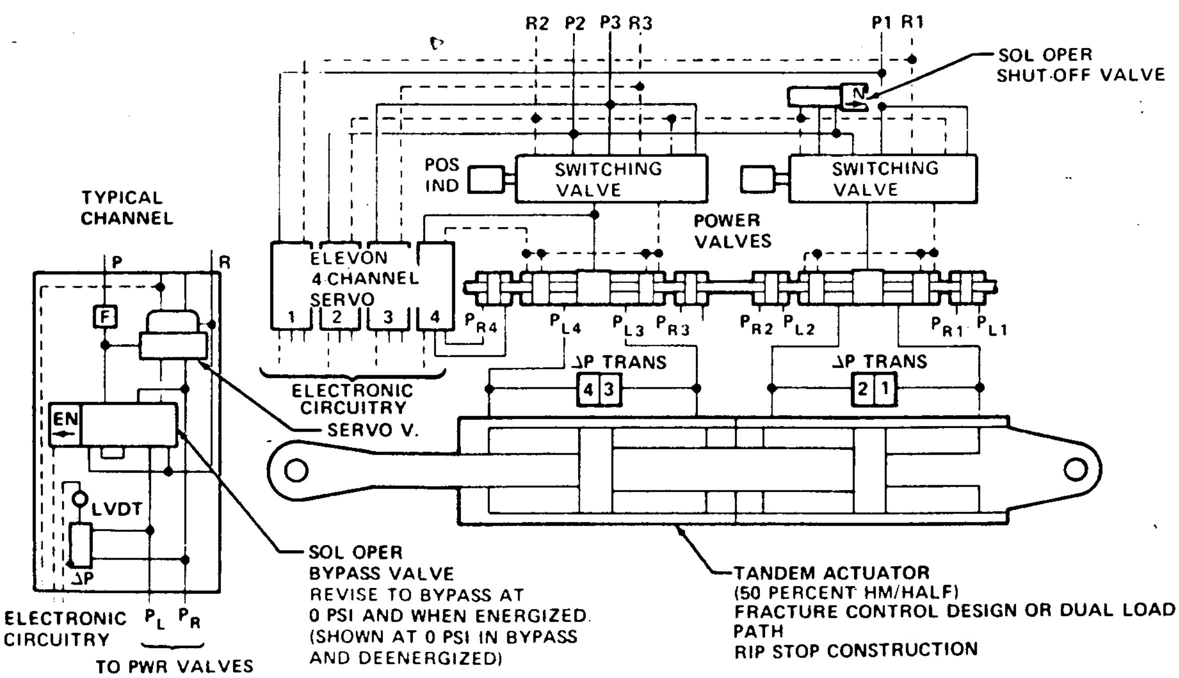
ELEVON ACTUATION

- **MDC PROPOSED TANDEM ACTUATOR PACKAGE**
  - ELIMINATES ALL SFP'S AS A PRESSURE VESSEL IN ACTUATOR PACKAGES
    - 76 COMPONENTS NO LONGER CRITICALITY CATEGORY I ITEMS
  - REROUTES SYSTEMS WITHIN ACTUATOR PACKAGES
    - SUPPLIES SEPARATE POWER TO EACH CHANNEL OF EXISTING FOUR-CHANNEL SERVO
  - EACH HALF OF ACTUATOR PRODUCES APPROXIMATELY 50 PERCENT DESIGN HINGE MOMENT
  - NORMAL OUTPUT 100-PERCENT DESIGN HINGE MOMENT WITH ANY TWO HYDRAULIC SYSTEMS OPERATIVE

MCDONNELL DOUGLAS
SPACE SHUTTLE ASSESSMENT

TANDEM ELEVON ACTUATOR

MDC PROPOSED DESIGN



MCDONNELL DOUGLAS

SPACE SHUTTLE ASSESSMENT

ORBITER ASSESSMENT

ELEVON ACTUATION

(CONT)

- IMPROVED SURFACE RATES FOR NORMAL OPERATION
  - HALF OF ALL TANDEM ACTUATORS SUPPLIED BY SAME PRIMARY SYSTEM
  - FLOW REQUIRED NOT INCREASED WHEN ROLL CONTROL SUPERIMPOSED ON PITCH CONTROL
- NORMAL SURFACE RATES FOR SINGLE SYSTEM OPERATION
  - SOL OPER VALVE SHUTOFF WHEN ONLY ONE HYDRAULIC SYSTEM IS OPERATING
    - ONLY 50 PERCENT FLOW REQUIRED ON ALL ACTUATORS
  - PRODUCES ADEQUATE HINGE MOMENT FOR LANDING
    - q REDUCED FOR SLOWER SPEEDS
    - LOADS REDUCED

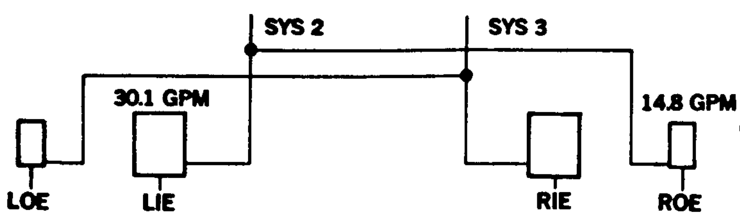
MCDONNELL DOUGLAS

SPACE SHUTTLE ASSESSMENT

ORBITER ASSESSMENT

ELEVON ACTUATION

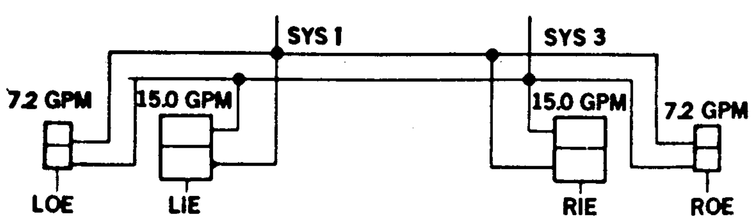
EXISTING SYSTEMS ARRANGEMENT



GPM/SYS
PITCH 20°/S
30.1 LIE
+14.8 ROE
44.9
ROLL 20°/S
+30.1 LIE
—14.8 ROE
15.3

COMBINED 44.9+15.3=60.2 GPM/SYS

MDC PROPOSED TANDEM ARRANGEMENT



GPM/SYS
PITCH 20°/S
7.2 LOE
15.0 LIE
15.0 RIE
7.2 ROE
44.4
ROLL 20°/S
+ 7.2 LOE
+15.0 LIE
—15.0 RIE
— 7.2 ROE
0

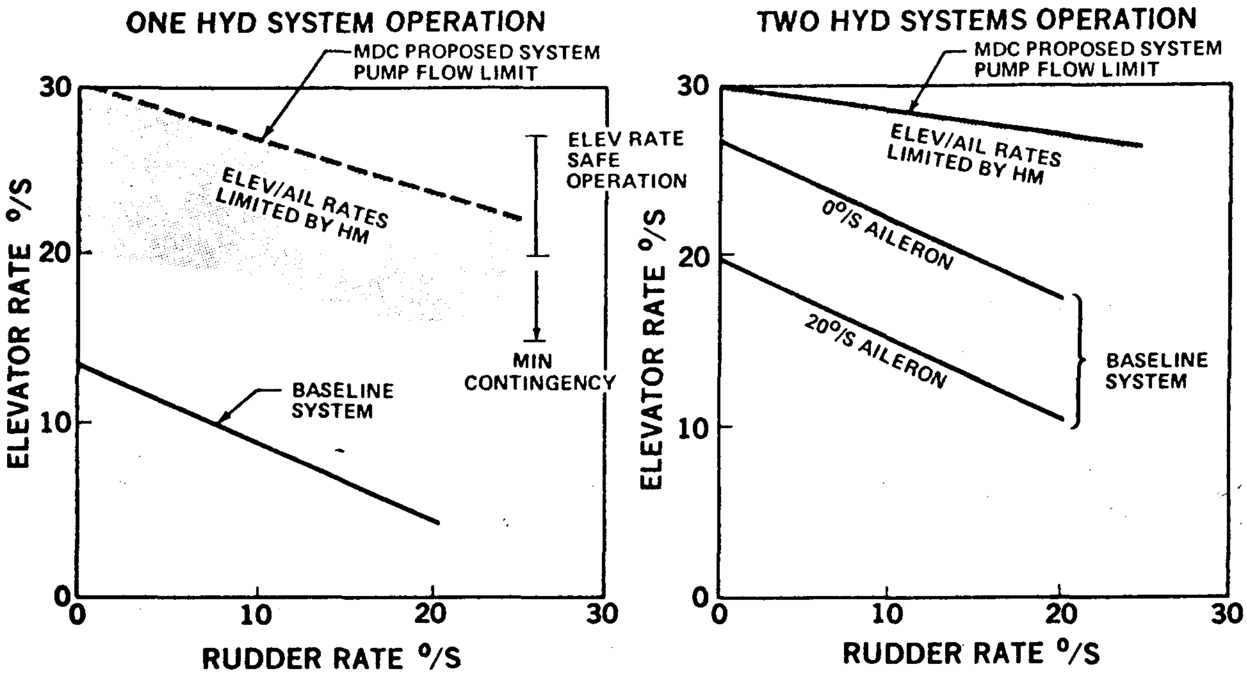
COMBINED 44.4+0 =44.4 GPM/SYS

25% REDUCTION IN FLOW REQUIRED

ORBITER ASSESSMENT

SURFACE RATE CAPABILITIES

MDC PROPOSED SYSTEM VERSUS BASELINE SYSTEM



ORBITER ASSESSMENT

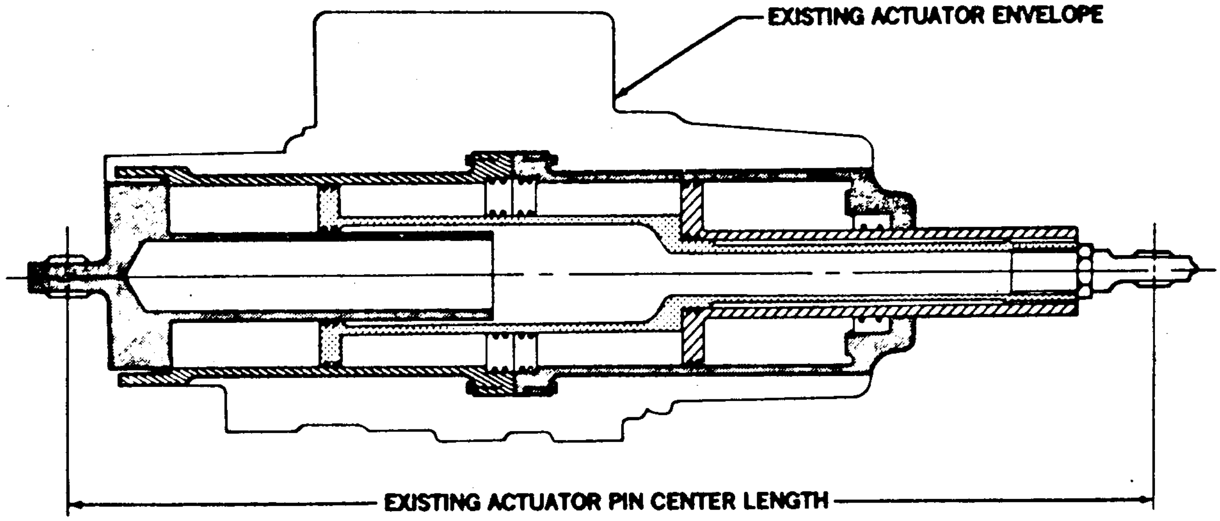
ELEVON ACTUATION

- MDC PROPOSED DESIGN (Cont'd)
  - SMALLER IN DIAMETER THAN EXISTING DESIGN
  - SAME PIN CENTER LENGTH
    - INTERNAL TAIL ROD
    - NO CHANGE IN WING STRUCTURE
    - NO CHANGE IN SUPPORT FITTINGS
  - RETAIN FOURCHANNEL SERVO
    - NO CHANGE IN ELECTRONIC CIRCUITRY
    - NO CHANGE IN ASA HARDWARE
  - RETAIN TWO SWITCHING VALVES AND CONTROL VALVE
  - ADD CONTROL VALVE AND SMALL SOLENOID OPERATED SHUTOFF VALVE
  - WEIGHT CHANGE LESS THAN 100 LB FOR ORBITER
  - WEIGHT SAVING POSSIBLE BY FUEL MANAGEMENT
  - COST ESTIMATE
    - EQUIVALENT TO CHANGE FROM H/R TO MOOG
    - (ROM) $5 M FOR 4 SHIP SETS AND FCHL
  - SCHEDULE IMPACT 15 MONTHS

MCDONNELL DOUGLAS

SPACE SHUTTLE ASSESSMENT

TANDEM ELEVON ACTUATOR
MDC PROPOSED DESIGN
INTERNAL TAIL ROD



MCDONNELL DOUGLAS

SPACE SHUTTLE ASSESSMENT

WEIGHT IMPACT

WEIGHT ESTIMATE (ROM)

SUBSYSTEM	ROCKWELL DELTA WEIGHT (LB)	MDC DELTA WEIGHT (LB)
WING STRUCTURE	+200	0
TAIL STRUCTURE (PDU SUPPORT)	+ 20*	0
HYDRAULIC ACTUATORS, LINES, FLUID	+640 (1240)***	+100
RUDDER/SPEED BRAKE PDU	+ 65	-20
ELECTRICAL AND AVIONICS	+ 60	0
TOTAL INERT WEIGHT CHANGE	+985**	+80

*ASSUMES NO ENVELOPE CHANGE IN TAIL STRUCTURE — OTHERWISE TAIL STRUCTURE ΔWEIGHT = + TBD

**ASSUMES NO APU'S CHANGE CONSUMABLES WEIGHT = + TBD

***WITH DUAL LOAD PATH ACTUATOR

MCDONNELL DOUGLAS

ORBITER ASSESSMENT

TANDEM ELEVON ACTUATOR

	EXISTING SINGLE ACTUATOR PACKAGE	MDC PROPOSED TANDEM ACTUATOR PACKAGE
o RIP STOP CONSTRUCTION	NO	YES
o SINGLE FAILURES DOWNSTREAM OF SWITCHING VALVES	LOSE ORBITER LOSE 3 HYDRAULIC SYSTEMS.	1/2 HINGE MOMENT AVAILABLE NORMAL LANDING (WILL NOT LOSE BOTH SYSTEMS 1 AND 3 WITH ANY SINGLE FAILURE)
o SINGLE HYDRAULIC FAILURE IN 4 CHANNEL SERVO	LOSE ORBITER LOSE 3 HYDRAULIC SYSTEMS.	FAIL OPERATIONAL NORMAL LANDING
o ALL SYSTEM OPERATIVE	COMBINED COMMANDED SURFACE RATES MARGINAL, THEREFORE PRIORITY RATE LIMITING WAS USED. (NOT SUCCESSFUL ON ALT 101).	COMBINED COMMANDED SURFACE RATES AVAILABLE WITHOUT PRIORITY RATE LIMITING
o FAIL ONE SYSTEM UPSTREAM OF SWITCHING VALVES	FAIL OPERATIONAL	FAIL OPERATIONAL
o FAIL SYSTEMS 1 AND 3 UPSTREAM OF SWITCHING VALVES	MAY LOSE ORBITER, SINGLE SYSTEM FLOW AND SURFACE RATE DEFICIENT AT LANDING	FAIL OPERATIONAL NORMAL LANDING
o FAIL SYSTEMS 1 AND 2 UPSTREAM OF SWITCHING VALVES	MAY LOSE ORBITER, SINGLE SYSTEM FLOW AND SURFACE RATE DEFICIENT AT LANDING	1/2 HINGE MOMENT AVAILABLE NORMAL LANDING
o FAIL SYSTEMS 2 AND 3 UPSTREAM OF SWITCHING VALVES	MAY LOSE ORBITER, SINGLE SYSTEM FLOW AND SURFACE RATE DEFICIENT AT LANDING	1/2 HINGE MOMENT AVAILABLE NORMAL LANDING

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MCDONNELL DOUGLAS

ORBITER ASSESSMENT

FLIGHT TEST ORBITER RELIABILITY

- MORE RISKS INHERENT IN FLIGHT TESTING
- IF ADDITIONAL RISKS ARE ACCEPTABLE FOR FLIGHT TESTING EXISTING ORBITER MAY BE USED FOR FLIGHT TESTS
- MINIMIZE RISKS BY INCORPORATING
    - "PEDIGREE" PROGRAM FOR
        - SSME-TVC ACTUATOR PACKAGES
        - RUDDER/SPEED BRAKE PDU
        - ELEVON ACTUATOR PACKAGE
    - LIMIT ON ORBIT TIME TO SHORTER MISSIONS
    - INCORPORATE OPERATIONAL REVISIONS AS SOON AS POSSIBLE
- FLIGHT TEST PROGRAM ESTABLISHES
    - CONFIDENCE LEVEL FOR HYDRAULIC SYSTEMS
    - VALIDITY OF REQUIREMENTS
- MAINTAIN FLEXIBILITY TO ALLOW FOR REQUIRED REVISIONS

MCDONNELL DOUGLAS

SPACE SHUTTLE ASSESSMENT

ORBITER ASSESSMENT SUMMARY

- INCORPORATE RECOMMENDED REVISIONS
  - SSME TVC ACTUATOR PACKAGES
    - FORTRESS PLAN
  - RUDDER/SPEED BRAKE HYDRAULIC PDU
    - MDC PROPOSAL
  - TANDEM ELEVON ACTUATOR PACKAGES
    - MDC PROPOSAL
- ELIMINATES 100 COMPONENTS FROM BEING CRITICALITY CATEGORY I HAZARD ITEMS
- INCREASES CONTROL SURFACE RATES AVAILABLE DURING CRITICAL APPROACH AND LANDING PHASE OF FLIGHT

MCDONNELL DOUGLAS

SPACE SHUTTLE ASSESSMENT

SPACE SHUTTLE HYDRAULIC SYSTEM ASSESSMENT

SUMMARY

MCDONNELL DOUGLAS

SPACE SHUTTLE ASSESSMENT

SPACE SHUTTLE

HYDRAULIC SYSTEM ASSESSMENT SUMMARY

- FINDINGS APPLY TO OPERATIONAL SHUTTLE
- BASELINE FOR ASSESSMENT IS OV102 CONFIGURATION
- RELIABILITY IS EQUAL TO TRANSPORT AIRCRAFT
- SFP ITEMS IDENTIFIED:

	TOTAL	CLOSED*	OPEN
• BOOSTER	234	180	64
• ORBITER	471	316	225
	705	496	289

* CLOSED — ADD'L TESTS INDICATED O.K.
— CORRECTIVE ACTION TAKEN

MCDONNELL DOUGLAS

SPACE SHUTTLE ASSESSMENT

SFP SUMMARY BOOSTER

NO.	ITEM	STATUS	QTY OF SFP'S	REMARKS	RESPONSE	EFFECTIVITY
1.0	SRB COMPONENTS					
1.1	SRB RESERVOIR OVERFILLING – RELIEF VALVE CAPPED	OPEN	SFC-4	LAUNCH HOLD WARNING FOR OVERFILL, UNCAP RELIEF VALVE		
1.2	SRB SERVICE DISCONNECT PANEL	OPEN	SFC-4	PROVIDE LOCK TO KEEP SHUTOFF VALVE FROM ROTATING IN PANEL		
1.3	PIPING AND HOSE FAILURE FROM PUMP RIPPLE AND SURGES	OPEN	SFC-4	PERFORM PUMP RIPPLE TESTS		
1.4	SWITCHING VALVE JAMMED – TVC	OPEN	4	ADD INLET SCREENS TO REDUCE CHANCE FOR JAMMING		

SFP SUMMARY
BOOSTER (CONT)

NO.	ITEM	STATUS	QTY OF SFP'S	REMARKS	RESPONSE	EFFECTIVITY
1.5	POWER VALVE JAMMED – TVC	OPEN	4	ADD INLET SCREENS TO REDUCE CHANCE FOR JAMMING		
1.6	LOCK VALVE JAMMED – TVC	OPEN	4	ADD INLET SCREENS TO REDUCE CHANCE FOR JAMMING		
1.7	PISTON SEAL FAILURE	- OPEN	4	ADD BARRIER SEAL		
1.8	FAILURE OF SWITCHING VALVE TO FUNCTION PROPERLY – TVC			NOTE: THIS RESULTS IN A CRIT 1U CONDITION		
	SEAL NO. 2	OPEN	4	WHEN COMBINED WITH LOSS OF A HYDRAULIC SYSTEM. ADD CHECK VALVES AT INLET		
	SEAL NO. 3	OPEN	4			

SFP SUMMARY
BOOSTER (CONT)

NO.	ITEM	STATUS	QTY OF SFP'S	REMARKS	RESPONSE	EFFECTIVITY
1.9	LOSS OF TVC ACTUATOR PACKING GLAND	OPEN	8	PROVIDE POSITIVE LOCK		
1.10	TVC ACTUATOR STRENGTH MARGINS NOT VERIFIED	OPEN	18	REEXAMINE DAMAGE TOLERANCE ANALYSIS		
1.11	SINGLE EXPLOSIVE EVENT NEAR STA 1307 CAN LOSE 3 SYSTEMS	OPEN	SFC (MANY)	REGROUP SYSTEMS ON STA 1307 AND PROVIDE BARRIERS		

MCDONNELL DOUGLAS

SPACE SHUTTLE ASSESSMENT

SFP SUMMARY
ORBITER (CONT)

NO.	ITEM	STATUS	QTY OF SFP'S	REMARKS	RESPONSE	EFFECTIVITY
2.0	ORBITER COMPONENTS					
2.1	ORBITER HYDRAULIC PUMP PRESS RIPPLE NOT COMPLETELY IDENTIFIED	OPEN	3	NEED ADDITIONAL TEST DATA		
2.2	ORBITER HYDRAULIC PUMP CASE DRAIN LINE SURGES MAY EXCEED PUMP CASE OR SHAFT SEAL STRENGTH LIMITS	OPEN	3	NEED ADDITIONAL TEST DATA		
2.3	ABRUPT LINE SIZE REDUCTION AT "T" FITTINGS	OPEN	MANY	STEP DOWN LINE SIZE IN SMALLER INCREMENTS		
2.4	HYDRAULIC FLUID LEAKAGE EFFECTS ON TPS AND HYDRAZINE LINE INSULATION	OPEN	MANY	PROVIDE LEAKAGE SUMPS AND SEAL FAYING SURFACES OF FUSELAGE SKIN		
2.5	HYDRAULIC FLUID LEAKAGE ON HOT APU EXHAUST	OPEN	3	PROVIDE CONVOLUTED SCREEN TO PREVENT DIRECT IMPINGEMENT OF FLUID ON HOT SURFACES		

MCDONNELL DOUGLAS

SPACE SHUTTLE ASSESSMENT

SFB SUMMARY
ORBITER (CONT)

NO.	ITEM	STATUS	QTY OF SFP'S	REMARKS	RESPONSE	EFFECTIVITY
2.6	FREON LEAKAGE INTO HYDRAULIC SYSTEM	OPEN	NUMEROUS	TEST EACH HEAT EXCHANGER		
2.7	ORBITER WHEEL BRAKE HOSES AND PIPING BREAKAGE	OPEN	SFC-2	RELOCATE ONE PAIR TO FORWARD SIDE OF SHOCKSTRUT		
2.8	LEAKS FROM BRAKE CONTROL MANIFOLD BETWEEN SWITCHING VALVE AND FLOW LIMITER	OPEN	NUMEROUS	A. BACKUP LEE PLUGS B. ADD BARRIER TO SEALS C. PERFORM DAMAGE TOLERANCE ANALYSIS		
2.9	POWER VALVE JAMMED SSME-TVC, ELEVON, R/SB, BODY FLAP	OPEN	19	ADD INLET SCREENS AND JAMPROOF VALVES		

MCDONNELL DOUGLAS

SFP SUMMARY
ORBITER (CONT)

NO.	ITEM	STATUS	QTY OF SFP'S	REMARKS	RESPONSE	EFFECTIVITY
2.10	PISTON ROD GLAND RETENTION – ELEVON ACTUATORS	OPEN	8	PROVIDE POSITIVE LOCK		
2.11	R/SB MANIFOLD UNION SEALS	OPEN	16	RELIEVE SURFACE TO MINIMIZE SEPARATING FORCE TEST		

MCDONNELL DOUGLAS

SFP SUMMARY
ORBITER (CONT)

NO.	ITEM	STATUS	QTY OF SFP'S	REMARKS	RESPONSE	EFFECTIVITY
2.12	R/SB BRAKE FAILURE OFF	OPEN	6	PROVIDE REDUNDANT BRAKE MECHANISM		
2.13	RUPTURE OF HYDR PRESS. AND RET LINES TO R/SB MOTOR	OPEN	12	ADD NO-BAK TO OUTPUT SHAFT		
2.14	BODY FLAP BRAKE FAILURE	OPEN	3	PROVIDE REDUNDANT BRAKE MECHANISM		
2.15	ACTUATORS NEED FRACTURE CONTROL ANALYSIS	OPEN	14	IMPLEMENT AS SOON AS POSSIBLE		
2.16	PRESSURE VESSEL FAILURES DOWNSTREAM OF SWITCHING VALVE. R/SB	OPEN	24 (+84 BOLTS)	PDU REDESIGN (PER DAC)		
2.17	ELEVON ACTUATORS – INADEQUATE RATE AND FAILURES DOWNSTREAM OF SWITCHING VALVE	OPEN	76 (+312 BOLTS)	ELEVON REDESIGN (PER DAC)		

SPACE SHUTTLE

HYDRAULIC SYSTEM ASSESSMENT

SUMMARY (CONTINUED)

BOOSTER ARCHITECTURE	2 REDUNDANT SYSTEMS ACCEPTABLE
ORBITER ARCHITECTURE	3 REDUNDANT SYSTEMS ACCEPTABLE
POWER SUPPLY	APU/PUMP ACCEPTABLE
HORSEPOWER	DEFICIENT FOR ELEVONS EXCESS FOR R/SB
CONTROL SYSTEMS	
SRB TVC	IMPOSE FORTRESS CONCEPT
SSME TVC	IMPOSE FORTRESS CONCEPT
SSME FUEL CONTROL	ACCEPTABLE
BODY FLAP	ACCEPTABLE
RUDDER/SPEED BRAKE	REPLUMB TO MINIMIZE SFP'S
ELEVONS	INSTALL TANDEM ACTUATORS AND REPLUMB TO MINIMIZE SFP'S

APPENDIX C

DOCUMENTATION RECORDS

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C.1 TECHNICAL DOCUMENTS AND REPORTS

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HISTORICAL DATA FROM JSC
DOCUMENT

DOC. NO.		
1.1	Space Shuttle Main Engine Hydraulic System (Briefing)	
1.2	Shuttle Critical Seals Presentation to J. Yardley, SSV76-36, August 27, 1976 (Document)	
1.3	E&D Summary Review of the Orbiter Hydraulic System, September 21, 1976 (Briefing)	
1.4	Hydraulics Systems Assessment Review, SSV76-38, September 22, 1976, (Document)	
1.5	SRB TVC Sytem, September 22, 1976 (Briefing)	
1.6	SRB TVC Actuator, October 1976 (Briefing)	
1.7	SRB TVC Hydraulic System Assessment, October 1976 (Briefing)	
1.8	Space Shuttle Ascent Flight Control Requirements, November 1976, (Briefing)	
1.9	Shuttle Hydraulics Assessment, December 23, 1976, (Memo to Associate Administrator for Space Flight)	
1.10	Status and Closeout of Recommendations of Dr. W. C. Williams' Hydraulic Review, March 30, 1977 (Memo to Manager, Space Shuttle Program)	
1.11	Space Shuttle Systems Failures Resulting in SSME Shutdown, April 2, 1976 (Memo to Manager, Space Shuttle Program)	
1.12	SSV77-32 (Only Hydraulic Related Sections included)	Orbiter 102 Critical Design Review Subsystem Briefings (Preliminary Draft)
1.13	MC621-0061A	Body Flap - Structure Technical Requirements
1.14	SD75-SH-0003	Hydraulics/Shuttle Critical Items List - OV-102
1.15	SD75-SH-0007A (2)	OV-102 Orbital Flight Test Configuration Failure Mode Effects Analysis - Rudder/Speedbrake and Body Flap Actuation Subsystems
1.16	SD75-SH-0011A (2)	OV-102 - Orbital Flight Test Configuration Failure Mode Effects Analysis - Hydraulic Subsystem

ADDITIONAL HISTORICAL DATA FROM JSC DOCUMENT

DOC. NO.

2.1 SSV76-46, Orbiter Hydraulic Subsystem Assessment Review, November 3, 1976.

2.2 SSV77-7, Rudder/Speedbrake and Body Flap Mechanical Systems Design Assessment (W. D. Wilkerson Committee), February 9, 1977

2.3 Single Point Failures Review of R/SB, Body Flap and Hydraulic Motors, March 1977.

2.4 SSV77-17, Hydraulic Subsystem Review (Williams, Yardley, & Malkin), April 1, 1977

2.5 Briefings on Selected Single Point Failures:

2.5.1	Landing Gear Actuators	February 15, 1977
2.5.2	Broken Shafts (R/SB & BF)	March 11, 1977
2.5.3	Jammed Gear Boxes	April 14, 1977
2.5.4	Clogged Filters	April 14, 1977
2.5.5	Jammed Spools	April 14, 1977

Date and From		DOC. No.	Document	DFG	CIG	DMG	DLE	JL
8/24/7	NASA Trip	3.1	Flight Control Review 10/5/76					
8/24/7	NASA Trip	3.2	SRB TVC Actuator System Model 19 Jul 76			9/1		
8/24/7	NASA Trip	3.3	SRB TVC Subsystem Description Sept. 76 13A10130			9/1		
8/24/7	Jim Cham.	3.4	Hyd System Safety Verification Questions Sept. 76			9/1		
8/24/7	NASA Trip	3.5	SRB TVC System Design 3 Apr 75			9/1		
8/24/7	NASA Trip	3.6	FCHL Test Plan SD74-SH-0265B	9/2	9/2			
		3.7	PCRB Level II 7/20/77					
		3.8	PCRB Level II 8/20/77					
9/1/7	Alex Kale	3.9	Reliability Requirements Table 5/12/75 RA-M025282			9/2		
9/1/7	Alex Kale	3.10	R&S Desk Inst. (RI) 400-1 Hazard Anal. Proc.			9/2		
9/1/7	Alex Kale	3.11	R&S Desk Inst. (RI) 400-3 Safety & Trade St.			9/2		
9/1/7	Alex Kale	3.12	R&S Desk Inst. (RI) 400-7 Hazard Tracking Proc.			9/2		
9/1/7	Alex Kale	3.13	R&S Desk Inst. (RI) 200-1 RFP Proc. Pkg Prep.			9/2		
9/1/7	Alex Kale	3.14	Sys. S Requirements for Suppliers and Subcontractors			9/2		
9/1/7	Alex Kale	3.15	Revision Notice to JSC 10888C (Chg 2) 10 Aug 77			9/2		
9/1/7	Alex Kale	3.16	Space Shuttle Orbiter/System Integ. Cont. Mgm't Plan			9/2		
8/24/7	NASA Trip	3.17	Alt Project Safety Assessment			9/1		
8/24/7	NASA Trip	3.18	S,R,M&QA Provisions for SS NHB 5300-4(10-1)			9/1		
8/24/7	NASA Trip	3.19	Major Safety Concerns, Space Shuttle Program			9/1		
8/24/7	NASA Trip	3.20	Servo Actuator, Elevon MC621-0014 (OV101)			9/1		
9/13/7	S. Truelock	3.21	OV-102 CDR, S Analysis Rpt, Vol. III, Mech. System			9/13		
9/12/7	S. Truelock	3.22	S Analysis Rpt, Cmts on Hazard Anal. CDR OV102			9/12		
9/12/7	S. Truelock	3.23	Shuttle Orbiter OV-102 CDR S Anal. Rpt, Vol. V			9/9		
9/9/7	Bob White	3.24	Definition of Shuttle Criticalities			9/9		
9/20/7	F. Elam	3.25	Rpt. Aerosurface Redun. Mgt for SS HI 3/5/76					
9/1/7	Alex Kale	3.26	R&S Desk Inst. 400-2 Safety Requirements			9/9		
9/20/7	Bob White	3.27	Hyd Subsystem Req'ts SD72-5H-0102-6 Rev. 1/3/77					
9/20/7	Bob White	3.28	CCB Briefing & MCR from W. Williams MCR 4313 SEP 1,77	9/20				
9/20/7	Bob White	3.29	OV-101 Main & Nose Landing Gear Cert. Tests Jun 77(RI)					
9/20/7	Bob White	3.30	Reqm't/Defn Doc. Aero Flt Cont Subsys. Vol 2-9 28 Oct75					
9/20/7	White/Elam	3.31	Summary of Undetected Failures (Working papers)					
9/21/7	Alex Kale	3.32	FMEA Instructions, Pg's 8-16 & 27; D1 100-2D					
9/21/7	Alex Kale	3.33	OV102 OFT FMEA LDG/DECEL SD75-SH-0009A					
9/27/7	Dick Perry	3.34	JSC PRACA, JSC 09296 Sep. 76					
9/27/7	Dick Perry	3.35	JSC Shuttle Full Prob Rpt (Comp Printout) 9/15/7					
9/27/7	Bob White	3.36	APU Usage Timeline for OFT 1, Memo 14 Sep 77					
9/27/7	Bob White	3.37	Hyd Sys Thermal Condition CR 2598					
9/27/7	Bob White	3.38	3 APU/HYD Systems MCR 0653-R3					

Date and From	Doc. No.	Document	DFG	CIG	UMB	CLE	JL
10/2/7 Bob White	3.39	Minutes Hyd Servoact Des Rev 8/23/7 @ RI					
10/11/7 Bob White	3.40	Orbiter Tubing Cert TSR 9/30/77 w/ltr ES2-587-77					
10/11/7 Bob White	3.41	Orbiter Tubing Verif. Plan SE 75-SH-0205A Oct. 76					
10/11/7 Bob White	3.42	FMEA Moog SSME-TVC Servoact MR R-1970, Rev. B 7/20/7					
10/11/7 Bob White	3.43	MCR 3 APU/Hyd Systems Rev. 4 1/14/77					
9/12/7 Bob White	3.44	Minutes & PRCB Dir for Level II PRCB/Sys Rev. Aug. 29, 77					
10/14/7 Alex Kale	3.45	Actuator Control Plan 6/16/75 SD 75-SH-0157					
10/14/7 Alex Kale	3.46	Shuttle Master Verif Plan, Rev. B JSC-07700-10-MVP-10					
8/17/7 Bob White	3.47	OV102 CDR Subsystems Briefings SSV77-32 1 Aug 77					
10/25/7 Bob White	3.48	OFT-1 CRIT Functions Assmt Mission Phases SSV77-38R 10/16/7					
10/27/7 Alex Kale	3.50	OV-102 FMEA 05-6G Hyd/Avionics SD75-SH-0181A					
10/28/7 Bob White	3.51	JSC/FOD Dwg's (3 copies) 12.2 (Item 24)					
10/31/7 Bob White	3.52	Abex Pump Qual Test - 4 vol's					
11/7/7 Bob White	3.53	Alt Hyd Sys Cert Test & Anal SD-77-SH-0229					
11/14/7 Alex Kale	W3.32	FMEA Instruction, Pgs 18 to 22 DI 100-2D					
11/23/7 Alex Kale	W3.32	FMEA Instructions, DI No. 100-2D R.I. 7/17/75					
11/11/7 Bob White	3.54	Requirements/Definition Doc Ldg/Decel Subsys SD72-SH-0102-1					
12/5/7 Bob White	3.55	RI ltr to JSC, Updates of Math Models/Act Sys 11/10/77					
12/5/7 Bob White	3.56	Level II PRCB/Sys. Review Minutes 25 Oct. 77					
12/6/7 Dale Haines	3.57	OV-102 Reservoir Press. Sys. RI Letter 1 Sept 77					
12/5/7 Bob White	3.58	OV-101 Hyd. Hardware Blkhd 1307 Acoustic Test 11/29/77					
12/5/7 Bob White	3.59	Documentation Request, JSC ltr to RI 10/26/77					
12/5/7 Bob White	3.60	Cryotanking/SSME Chilldown Test JSC Msg to RI 11/77					
12/8/7 Bob White	3.61	Seal Tests NASA JSC Memo dated 8/27/76					
12/19/7 Bob White	3.62	Space Shuttle CDR Minutes (Oct 27, 77) dated 11/8/77					
12/19/7 Bob White	3.63	Low Cost Sys for Emerg Hyd Power on FMDF, NASA ltr 12/8/77					
1/18/8 S. Truelock	3.64	Special FMEA for Orbiter Elevon Act's 1/10/78					
1/18/8 S. Truelock	3.65	Orbiter Fluid Venting, TIR 5-2630-2692 1/18/77					
1/18/8 S. Truelock	3.66	Nonredundancy of Static Hyd Fluid Seals; 0-22 3/4/77					
1/18/78 S. Truelock	3.67	Orbiter Nose & Main Ldg Gear Deployment; 0-17 6/28/76					
1/23/8 Wes G.	3.68	Actuator Control Plan SD-SH-0157 & Chg No. 1 8/27/77					
1/24/8 Wes G.	3.69	FCHL and OV-101 Response to Pump Ripple 2/11/77 ← [illegible]					
1/30/8 Bob White	3.70	Report, Structural Anal. Moog SE06, Rev. F 10/14/77					
2/8/8 Bob White	3.71	Elastomeric Seals Study for SSME Act. 12/3/76					
2/28/78 Bob White	3.72	Minutes of ORB/R.I. Tech Status Rev. 1/19/78					
3/1/78 Bob White	3.73	Structural Analysic Rpt. (SSME-TVC) MOOG 7/20/77					
3/6/8 Bob White	3.74	Moog Dwg's Flange; Servo Face; Leakage Control					
3/3/8 Steve T.	3.75	JSC-0770, Vol. X Reli Req'ts & Dev/Waivers Authorized					

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Date and From		DOC. No.	Document	DFG	CHG	DMB	DEE	JL
3/13/8	Steve T.	3.76	Major Safety Concerns Space Shuttle Program 2/17/78 JSC0999F					
3/23/8	Steve T.	3.77	JSC-07700, Vol. X, Para. 3.4.4.1 (pg's 3-91 to 93; 107 to 109)					
3/24/8	Bob W.	3.78	Orbital Flt Test, SD76-SH-0022, Vol. 3 2/24/78					
4/6/8	Bob W.	3.79	Aerosurface Servo Amp/Act Integ. Testing JSC-13816 1/78					
✓ 4/28/8	Bob W.	3.80	R.I. Req. for App. of APU Potential Ig. Temps 4/19/78					
5/15/8	Bob W.	3.81	Minutes ORB Level III CCB 4/10/78					
5/15/8	Bob W.	3.82	Schematic - Hyd Subsystem, ORB VFT V570-580997					
5/26/8	Bob W.	3.83	Orbiter Brake Tests - ER 4668 7/26/77					
6/2/8	Bob W.	3.84	Ltr to NASA Dr. Williams Hyd Review Action Items 5/22/78					
6/7/8	Bob W.	3.85	JSC Review of MDC Hyd Assessment Int.Problem List 6/78					
6/7/8	Bob W.	3.86	JSC Review Request of MDC Assessment Concerns of Dec. 77 6/2/78					
6/14/8	Bob W.	3.87	Minutes & PRCB Div's for Spec. Lev. II PRCB 5/16/78					
7/6/8	Bob W.	3.88	MAC DAC Hyd Assessment Review (R.I.) 7/5/78					
7/12/8	F. Slemmer	3.89	Seller Config. Baseline Doc. Moog 4/28/78					

Date and From		Doc. No.	Document	D/G	C/G	D/B	DEL	JL
9/21/7	Jim C.	4.1	R/SB HVM 3rd Rev. Sund/RI/NASA @ Moog 7, 8, 9 Sep 77					
9/21/7	Jim C.	4.2	Moog CDR, RID Elect Ave Marking 9/7/77					
9/21/7	Jim C.	4.3	Moog CDR, RID Material Usage Rationales 8/30/77					
9/21/7	Jim C.	4.4	R/SD HVM Dwg Review Notes (undated)					
9/21/7	Jim C.	4.5	Data & Dwg. Rev. Moog Hyd Valve Mod, Conts 9/2/77					
9/21/7	Jim C.	4.6	Minutes, Sp. Level II PRCB, SRB CIL Reg. Cha 9/6/77					
9/21/7	Jim C.	4.7	RID JSC-1, Lack of Stress Anal/Test Data 7/27/7 TVC ACTR					
9/21/7	Jim C.	4.8	RID M-E-63, A07905 Retainer, Threaded (ND) ELEVON					
9/21/7	Jim C.	4.9	RID 483043-CDR-B001, Lee Jet Barrier 8/10/7					
9/29/7	Jim C	4.10	OV102 TCS Heater Status Aug. 10, 77					
9/29/7	Jim C	4.11	Fail Det & ISO (FDI) Cert Elevons & R/SB					
11/8/7	Jim C.	4.12	Data on Alt Flight 5 Landing Memo 11/3/77					
1/3/8	Jim C.	4.13	Vol. II, Sect 5, SD73-SH-0097-2E, SSFCDB-ORB June 76					
1/31/8	Jim C.	4.14	APU Hydrazine Hot Surface Ig. Eval. TSR Jan. 78					
1/31/8	Jim C.	4.15	Fire/Toxicity Safety Guidelines SD75-SH-0241 3/19/76					
2/8/8	Jim C.	4.16	DEV/Waivers Authorized (MJ07700-001, Vol. X)					
2/23/8	Jim C.	4.17	Contaminated Tile Vib. Test TPS #V-GES-135 1/13/78					
5/23/8	Jim C.	4.18	Longitudinal Control Performance on FF5 (undated)					
7/6/78	Jim C.	4.19	Aerosurface Hinge Mom. & Rates/Hyd Sys. Design 7/5/8					

*ND = No Date

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Date and From	Doc No.	Document	DFG	CIG	DHS	DCE	JL
9/30/7 Geo. Butler	5.1	SRB Problem Report Summary 7 Sept. 77					
10/4/7 Zack T.	5.2	EI Spec, Part 1, SRB TVC CP013M00001 4/4/77					
10/4/7 Zack T.	5.3	SRB System Data Book Vol. I SE0190832H(A) 6/77					
10/4/7 Zack T.	5.4	SRB System Data Book Vol. II SE0190832H(A) 6/77					
10/4/7 Zack T.	5.5	SRB TVC Overall System Test Requirements 10/1/76					
10/4/7 Zack T.	5.6	Requirements/DEF Doc. 3 & 4 SRM ST Test Art 4/77					
10/10/7 Geo Butler	5.7	Filter MDM Failure Report No. 00009 Aug. 4, 77					
10/10/7 Geo Butler	5.8	Quick Disc. Coup. Fail Rept No. 77-1086-DP Kaiser Jul 19, 77					
10/10/7 Geo Butler	5.9	Quick Disc Coup. Fail Rept No. 77-1087-DP Kaiser Jul 19, 77					
10/10/7 Geo Butler	5.10	Quick Disc Coup. Fail Rept No. 77-1088-DP Kaiser July 19, 77					
10/10/7 Geo Butler	5.11	Quick Disc Coup. Fail Rept No. 77-1090-DP Kaiser Jul 19, 77					
10/10/7 Geo Butler	5.12	Pump Shaft Broken DR 1559 MSFC Aug 23, 77					
10/10/7 Geo Butler	5.13	Random Small Amp/Freq Piston Motion PRR 001 Moog 8/1/77					
10/10/7 Geo Butler	5.14	Low Turbine Speed SRB 13/21223 Sundstrand Jul 27, 77					
10/10/7 Geo Butler	5.15	APU Failed to Start SRB 11/21215 Sundstrand Jul 25, 77					
10/17/7 Geo Butler	5.16	SRB Problem Report Summary Oct. 7, 77					
10/20/7 Geo Butler	5.17	SRB CEI Spec, Part I CP013M00000B Apr 18, 77					
10/20/7 Geo Butler	5.18	SRB Verif. Plan SE-019-019-2H, Rev. A Jun 2, 77					
10/20/7 Geo Butler	5.19	MSFC B & QA Plan for SRB SE-020-005-2H Oct. 12, 76					
11/8/7 Walt J	5.20	Abex FMEA Pump, Hyd Var Del Rev. 6/8/76					
11/8/7 Walt J.	5.21	Moog FMEA/CIL MR R-2200, Sec. 3 & 5 Rev. 5/11/76					
11/14/7 Geo Butler	5.22	SRB Problem Report Summary Nov. 8, 1977					
11/17/7 Moog Trip	5.23	Elastomeric Seals Study - SSME Act. MR E-2299 12/3/76					
12/21/7 Zack T.	5.24	MFSC-PROC-166D Cleaning, Testing, etc. Hyd's 2/7/67					
12/21/7 Geo Butler	5.25	SRB Problem Report Summary Dec. 12, 77					
1/9/8 Walt J.	5.26	SRB Assembly Checkout, O&M Reg & Spec SE-019-051-2H 12/15/77					
1/9/8 Walt J.	5.27	SRB Prelaunch O&M Reg & Spec SE-019-096-2H 8/1/77					
1/9/8 Walt J.	5.28	SRB Actuator Rate Reqmts; 1.3-TM-C0603-299 10/76					
1/9/8 Walt J.	5.29	MPS TVC Servoactuator Vib Test Events; R.I.					
1/12/8 Walt J.	5.30	FMEA for SRB SE 019-054-2H, Rev. C Nov. 1977					
1/23/8 Walt J.	5.31	Hazard Analysis for the SRB SE-019-101-2H Nov. 77					
1/25/8 Geo. Butler	5.32	SRB Problem Report Summary January 18, 1978					
1/31/8 Geo. Butler	5.33	CIL for SRB SE019-127-2H Nov. 77					
2/27/78 Geo. Butler	5.34	S.R.B. Problem Report Summary Feb. 17, 1978					
3/21/8 Geo. Butler	5.35	SRB Problem Report Summary Mar. 13, 1978					
3/29/8 Walt J.	5.36	Design Verification Vib. Test Report HR 73300073 4/15/77					
4/11/8 Walt J.	5.37	Seal Leakage Charts (Flow vs. Pressure) (undated)					
4/28/8 Walt J.	5.38	SRB Problem Report Summary April 24, 1978					

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Date and From	DOC. No.	Document	DFG	CHG	DMB	DEE	JL
5/12/8 Walt J.	5.39	Minutes Spec Level II PRCB-504499 4/26/78					
		(SRB & ORB TVC Mech. Feedback Assembly)					
5/18/8 Geo. Butler	5.40	SRB Problem Report Summary May 10, 1978					
6/27/8 Geo. Butler	5.41	SRB Problem Report Summary June 16, 1978					
7/18/8 Geo. Butler	5.42	SRB Problem Report Summary July 10, 1978					

C.2 SRB DRAWING LIST

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SPACE SHUTTLE DATA

SRB HYDRAULIC SUBSYSTEM

SPECIFICATION NUMBER		COMPONENT	SUPPLIER	PART NUMBER		ASSEMBLY NUMBER		PARTS LIST		LIST OF MATERIAL		REMARKS
	/	Layout APU Gearbox	Sundstrand Corp.	–	/	2644A-L8	–	–	/	–	/	
13A10036	G	Reservoir, Hydraulic	Arkwin	–	/	1711016-001	G	–	•	–	•	
13A10036	/	Head L.P. Assy	Arkwin	–	/	1711016-100	A	–	•	–	7	
13A10036	/	Cover Assy	Arkwin	–	/	1711016-103	B	–	•	–	/	
13A10036	/	Cylinder	Arkwin	1711016-200	A	–	/	–	/	–	•	
13A10036	/	Ring, Keeper	Arkwin	1711016-203	–	–	/	–	/	–	•	
13A10036	/	Ring, Keeper	Arkwin	1711016-213	–	–	/	–	/	–	•	
13A10036	/	Valve Relief, SCD	Arkwin	1711016-228	A	–	/	–	•	–	/	James, Pond, Clark P/N 532-8J7 (L3)-1
13A10037	C	Manifold Assy, TVC Fluid	Pneu Draulics Inc.	–	/	8090	H	–	•	–	•	
13A10038	H	Hydr Pump SCD	Abex	65120	C	63320	/	–	/	–	/	
13A10042	A	Check Valve and Filter Assy	Purolator	–	/	7582923	G	–	•	–	•	
13A10042	/	Indicator Filter ΔP	Purolator	–	/	7583010	B	–	•	–	•	
13A10050	D	Coupling, 3/4 In. Quick Discon Cap	Kaiser	–	/	0010-0043	A	–	•	–	/	
13A10050	/	Coupling, 3/4 In. Quick Discon Cap	Kaiser	–	/	0031-1036	B	–	•	–	/	
13A10050	/	Nipple Assy, 3/4 In. Q.D.	Kaiser	–	/	0061-0087	E	–	•	–	/	
13A10052	D	S/O Valve Manual,	Kaiser	13A10052-3	/	0217-0009	F	–	•	–	/	

C.3 ORBITER DRAWING LIST

LIST	HYDRAULIC RESEARCH & MANUFACTURING COMPANY VALENCIA, CALIFORNIA	CONTRACT NO. NAS8-27980	CODE IDENT 81073	DL34000550	REVISION LTR [illegible] DATE [illegible]
TITLE HYDRAULIC ACTUATION SYSTEM, S S M E		AUTHENTICATION			SHEET 1 OF 13 SHEETS

DWG SIZE	DOCUMENT NUMBER	SHEET NO.	REV LTR	NOMENCLATURE OR DESCRIPTION	
				DRAWINGS	
C	LMT-479T12	1	F	LINEAR TRANSDUCER ASSY	-
C	LMT-479T12-1	1	J	LINEAR TRANSDUCER ASSY	
C	LMT-479T12-2	1	C	HOUSING	-
C	LMT-479T12-3	1	D	RING	-
C	LMT-479T12-01	1	-	HOUSING	-
C	LMT-479T12-1-02	1	B	WASHER	-
C	LMT-479T12-1-03	1	B	SHIELD	-
C	LMT-479T12-1-04	1	-	WASHER	-
C	LMT-479T12-1-05	1	B	WASHER	-
C	LMT-479T12-1-06	1	D	CORE	-
C	LMT-479T12-1-07	1	A	END PLUG	-
C	LMT-479T12-1-08	1	-	TUBE	-
C	LMT-479T12-1-09	1	A	EXTENSION	-
C	LMT-479T12-1-10	1	A	END FITTING	-
D	ES104050	1	F	TRANSDUCER, ROTARY	-
D	104050	4	E	DUAL REDUNDANT ROTARY ASSY	-
D	104051	1	F	HOUSING ASSY latest available	-
C	104052	1	A	REAR HOUSING	-
C	104053	1	B	END PLATE, HOUSING ASSY	-
D	104054	1	B	STACK, HOUSING ASSY	-
D	104055	1	J	CALIBRATION SUBASSY latest available	-
D	104056	2	C	GUSSET, SPOOL TUBE ASSY	-
C	104057	1	C	PLATE, BEARING PRELOAD	-
C	104058	1	A	SHIELD CALIBRATION SUBASSY	-
C	104059	1	F	ROTOR ASSY, CALIBRATION SUBASSY	-
B	104060	1	E	MID BEARING ROTOR SUBASSY	-
C	104061	1	D	DRIVE BAR, PVOT DUAL ROTARY XDUCER	-
D	104062	2	E	ROTOR SUBASSY	-
D	104064	1	H	SPOOL TUBE ASSY latest available	-
D	104065	2	E	FLANGE, SPOOL TUBE ASSY	-

NO CHANGE A ADDED D DELETED R REVISED NR NOT RELEASED

LIST	HYDRAULIC RESEARCH & MANUFACTURING COMPANY VALENCIA, CALIFORNIA	CONTRACT NO. NAS8-27900	CODE IDENT 81073	DL34000550	REVISION LTR [illegible] DATE [illegible]
TITLE HYDRAULIC ACTUATION SYSTEM, S S M E		AUTHENTICATION			SHEET 2 OF 13 SHEETS

DWG SIZE	DOCUMENT NUMBER	SHEET NO.	REV LTR	NOMENCLATURE OR DESCRIPTION	
B	104067	1	E	BEARING CAP SPOOL TUBE SUBASSY latest available	
B	104068	1	C	SHIELD WASHER CALIBRATION SUBASSY	-
C	104069	1	C	SPOOL TUBE, SPOOL TUBE SUBASSY	-
D	104071	1	D	STATOR ASSY, DUAL	-
C	104072	1	B	RETAINING RING, STATOR ASSY	-
D	104073	1	F	STATOR SUBASSY "A"	-
A	104074	-	-	COIL SPECIFICATION	-
C	104075	1	B	FORWARD CAP, STATOR	-
B	104076	1	C	INSULATION WASHER, CALIBRATION SUBASSY	-
C	104077	1	C	END CAP, STATOR	-
B	104078	1	C	SHIELD	-
D	104079	1	D	STATOR CORE	-
C	104080	1	D	MID CAP, STATOR	-
C	104081	1	C	FORWARD HOUSING	-
D	104082	1	F	COIL WINDING ASSY	-
B	104083	1	D	BOBBIN TUBING COIL WINDING ASSY	-
C	104084	1	A	BOBBIN WASHER, COIL WINDING ASSY	-
C	104085	1	D	WINDING, AUXILIARY, BIFILAR WOUND	-
B	104086	1	A	SHIM	-
B	104087	1	B	THREADED BUSHING	-
C	104088	1	D	NUT PLATE ASSEMBLY, DUAL ROTARY TRANSDUCER	-
D	104089	1	D	WIRE TERMINAL BOARD ASSEMBLY	-
B	104099	1	A	BEARING SHIM ROTOR ASSEMBLY	-
B	104220	1	A	SHIELD, ROTOR	-
D	104223	1	B	STATOR SUBASSY "B"	-
B	104224	1	A	ROTOR, ISOLATOR	-
B	104225	1	A	ROTOR, BEARING PIVOT	-
C	104226	1	A	ROTOR, DRIVE SHAFT	-
C	104227	1	A	ROTOR, MAGNETIC ARMATURE	-
C	104267	1	A	WAVY WASHER	-
C	104274	1	A	WAVY WASHER	-
J	11-11634	2	K	FILTER ASSY, INLINE	-
D	21-13193	1	J	INLINE ELEMENT ASSY	-

O CHANGE A ADDED D DELETED R REVISED NR NOT RELEASED

A LIST	HYDRAULIC RESEARCH & MANUFACTURING COMPANY VALENCIA, CALIFORNIA	CONTRACT NO. NAS8-27980	CODE IDENT 81873	0L34000550	REVISION LTR DATE

TITLE	AUTHENTICATION	SHEET 3 OF 10 SHEETS
HYDRAULIC ACTUATION SYSTEM, S S M E		

DE T	DWG SIZE	DOCUMENT NUMBER	SHEET NO.	REV LTR	NOMENCLATURE OR DESCRIPTION	
	C	51-11284 ✓	1	G	TUBE, SUPPORT	-
	B	51-11285 ✓	1	D	COLLAR, FILTER	-
	C	51-11286 ✓	1	F	RETAINER, FILTER	-
	D	51-11287 ✓	1	G	FITTING, OUTLET	-
	D	52-11139 ✓	1	B	HOUSING, FILTER	-
	D	52-11311 ✓	1	D	FITTING, INLET	-
	C	× 54-10007	1	A	TEST FIXTURE FOR 11-11634	-
	D	61-10076 ✓	1	F	FILTER ASSY, INLINE	-
	C	61-10077 ✓	1	B	SUPPORT ASSY, FILTER, INLINE	-
	B	× 200363	1	F	PLATE, SHIPPING	-
	B	× 250443	1	A	WASHER	-
	A	20101160 ✓	6	C	SERVOSWITCH latest available	-
	D	20101161 ✓	1	B	SERVOSWITCH ASSEMBLY	-
	A	22255802 ✓	5	B	SERVOVALVE latest available	-
	D	22255803 ✓	1	A	SERVOVALVE ASSY	-
	B	× 28001032	1	B	PLATE, IDENT	-
	B	× 28001582	1	A	BALL	-
	C	28003029 ✓	1	B	SCREW, T M latest available	-
	C	28003031 ✓	1	C	COVER "	-
	C	28003032 ✓	1	B	COVER CASTING	-
	C	28003035 ✓	1	A	TORQUE MOTOR ASSY	-
	D	28003036 ✓	1	C	COIL, TORQUE MOTOR "	-
	C	28003037 ✓	1	B	SPACER - TUBE, ARMATURE AND CAP ASSY "	-
	C	28003038 ✓	1	B	COIL FORM "	-
	B	28003039 ✓	1	A	TUBE, STANDOFF "	-
	D	28003040 ✓	1	A	FRAME, UPPER "	-
	C	28003041 ✓	1	A	FRAME AND BALL ASSY "	-
	C	28003042 ✓	1	A	FRAME CASTING	-
	C	28003043 ✓	1	A	MAGNET #1 "	-
	C	28003044 ✓	1	A	MAGNET #2 "	-
	C	28003045 ✓	1	A	FRAME, LOWER #1 "	-
	C	28003046 ✓	1	A	FRAME, LOWER #2 "	-
	C	28003047 ✓	1	-	FRAME, LOWER	-

· NO CHANGE A ADDED D DELETED R REVISED NR NOT RELEASED

LIST	HYDRAULIC RESEARCH & MANUFACTURING COMPANY VALENCIA, CALIFORNIA	CONTRACT NO. NAS8-27980	CODE IDENT 81873	0L34000550	REVISION LTR DATE

TITLE	AUTHENTICATION	SHEET 4 OF 10 SHEETS
HYDRAULIC ACTUATION SYSTEM, S S M E		

E T	DWG SIZE	DOCUMENT NUMBER	SHEET NO.	REV LTR	NOMENCLATURE OR DESCRIPTION	
	C	28003048 ✓	1	A	FRAME CASTING	-
	D	28003049 ✓	1	-	ARMATURE ASSY	-
	C	28003050 ✓	1	-	ARMATURE & CAP latest available	-
	C	28003051 ✓	1	A	ARMATURE	-
	C	28003052 ✓	1	A	CAP	-
	C	28003053 ✓	1	B	FLAPPER latest available	-
	C	28003054 ✓	1	A	TUBE & SPACER "	-
	C	28003055 ✓	1	C	SPACER	-
	C	28003056 ✓	1	B	TUBE	-
	C	× 28003057	1	-	FEEDBACK & BALL	-
	C	28003058 ✓	1	A	FEEDBACK WIRE	-
	C	× 28003059	1	A	FLAPPER AND FEEDBACK	-
	B	× 28003060	1	D	ARMATURE STOP	-
	C	28003061 ✓	1	C	ARMATURE CASTING latest available	-
	C	28003062 ✓	1	A	END PLATE "	-
	C	28003063 ✓	1	D	ORIFICE & FILTER ASSY "	-
	C	28003064 ✓	1	-	ORIFICE STOP	-
	C	28003065 ✓	1	C	FILTER	-
	C	28003066 ✓	1	D	ORIFICE & RETAINER "	-
	C	28003067 ✓	1	-	RETAINER	-
	C	28003068 ✓	1	C	ORIFICE "	-
	B	28003069 ✓	1	B	BALL, SPECIAL "	-
	C	28003070 ✓	1	-	HOUSING & PIN ASSY	-
	B	28003071 ✓	1	A	PIN, LOCATING "	-
	C	28003072 ✓	1	D	HOUSING & SPOOL ASSY "	-
	D	28003073 ✓	1	-	SPOOL	-
	C	28003074 ✓	1	B	NOZZLE "	-
	C	28003075 ✓	1	A	HOUSING & SLEEVE ASSY	-
	D	28003076 ✓	1	C	SLEEVE (TAB) "	-
	D	28003077 ✓	1	A	SLEEVE BLANK	-
	C	28003078 ✓	1	-	HOUSING & PIN ASSY	-
	E	28003079 ✓	1	C	HOUSING latest available	-
	D	28003080	1	-	HOUSING CSTG	-

- NO CHANGE A ADDED D DELETED R REVISED NR NOT RELEASED

ATA LIST	Hydraulic Research Valencia, Calif.	Contract No. NAS 8-27980	Code Ident. 81873	DL 34000350
t Title HYDRAULIC ACTUATION SYSTEM, SSME			Authentication	

Dwg Size	Document Number	Sheet No.	Rev Ltr	Nomenclature Or Description
C	28003031	1	C	Orifice Damper latest available
C	28003032	1	-	Gasket
C	28003033	1	A	Stroke Limiter
B	28003092	1	B	Screw "
D	28003093	1	B	Cable Assy "
C	28003101	1	A	Shell "
C	28003102	1	A	Header "
B	28003182	1	C	Plug "
C	28003183	1	C	End Plate, C2
D	28003291	1	B	Coil, Torque Motor (Tab)
D	28003503	1	-	Spool
C	28003504	1	A	Flapper
C	28003505	1	-	Shell
C	28003506	1	-	Header
C	28003507	1	-	Cable Assy
C	28003508	1	-	Armature Assy
C	28003509	1	-	Torque Motor Assy
C	28003510	1	-	Housing and Spool Assy
C	28003511	1	-	Housing and Pin Assy
B	28003512	1	-	Stud
C	28003513	1	-	Flapper and Stud Assy
C	28003618	1	-	Housing and Sleeve Assy
C	28003619	1	B	Housing
B	22002655	1	A	Screw, Cap, Socket Head
C	28003704	1	-	Shell
C	28003705	1	-	Cable Assy
C	34000134	1	A	Spool-Sleeve Assy, Bypass Valve
	EO		B	

Change A Added D Deleted R Revised

ATA LIST	Hydraulic Research Valencia, Calif.	Contract No. NAS 8-27980	Code Ident. 81873	DL 34000350
t Title HYDRAULIC ACTUATION SYSTEM, SSME			Authentication	Sheet 6 of 13

Dwg Size	Document Number	Sheet No.	Rev Ltr	Nomenclature Or Description
C	34000135	1	A	Spool-Bypass Valve
	EO		B	
	EO		C	
D	34000136	1	D	Sleeve, Bypass Valve - Tab
B	34000137	1	-	Spool-Sleeve Assy, Shuttle Valve
C	34000138	1	B	Spool, Shuttle Valve
D	34000139	1	A	Sleeve, Shuttle Valve
B	34000142	1	A	Piston
B	34000143	1	-	Washer
B	34000144	1	B	Spring, Compression
C	34000145	1	A	Seat, Spring - Tab
B	34000146	1	B	Spring, Compression
C	34000147	1	F	Stop, Spring - Tab
B	34000148	1	A	Sleeve, Spring - Tab
D	34000149	1	C	Cap, End, Bypass and Shuttle Valve
B	34000153	1	B	Gasket, Torque Motor
B	34000159	1	B	Gasket, Servo
B	34000162	1	B	Gasket, Connector
B	34000163	1	B	Gasket
C	34000165	1	-	Shim, Sleeve
	EO		A	
B	34000192	1	B	Quill
D	34000194	1	A	Plate, Shipping
C	34000195	1	A	Plate, Shipping
C	34000196	1	D	Closure, Shipping Pressure Port
C	34000197	1	B	Closure, Shipping Return Port
C	34000198	1	C	Closure, Shipping Pneu. Port
C	34000199	1	C	Closure, Shipping Vent/Leak Test Port

Change A Added D Deleted R Revised

IST Hydraulic Research Valencia, Calif. Contract No. NAS 8-27930 Code Ident. 81873 DL 34000000

AULIC ACTUATION SYSTEM, SSME Authentication Sheet 7 of 13

Document Number	Sheet No.	Rev Ltr	Nomenclature Or Description	
340[illegible]9 ✓	1	C	Billet - PVA and CCVA	-
34000228 ✓	1	A	Billet - MPVA *latest available*	-
34000232 ✓	1	B	Spring, Compression	-
34000233 ✓	1	A	Seat, Spring	-
34000234 ✓	3	F	Housing Assembly	R
34000235 ✓	3	J	Housing Assembly	R
34000237 ✓	2	B	Housing, Formed	-
34000238 ✓	2	B	Housing, Formed	-
34000239 ✓	1	-	Insert	-
34000243 ✓	1	N	Shaft Assy, Output	-
34000244 ✓	1	A	Shim, Shaft	-
34000245 ✓	1	-	Spacer	-
34000247 ✓	1	B	Retainer *latest available*	-
34000248 ✓	1	-	Shim, Crank	-
34000249 ✓	1	D	Cover Assembly	-
EO ✓		E		
34000254 ✓	1	E	Pin	-
34000256 ✓	1	G	Rod	-
34000257 ✓	1	-	Shim, Hyd.	-
EO ✓		A		
34000258 ✓	1	A	Cap, Hyd.	-
34000259 ✓	1	E	Piston, Hyd.	-
EO ✓		F		
34000262 ✓	1	A	Piston, Pneu.	-
34000263 ✓	1	G	Cap, Pneu.	-
34000264 ✓	1	-	Shim, Pneu.	-

A Added D Deleted R Revised

LIST Hydraulic Research Valencia, Calif. Contract No. NAS 8-27930 Code Ident. 81873 DL 34000000

RAULIC ACTUATION SYSTEM, SSME Authentication Sheet 8 of 13

Document Number	Sheet No.	Rev Ltr	Nomenclature Or Description	
34000293 ✓	1	A	Insert	-
34000296 ✓	1	K	Shaft Assy	-
34000[illegible] ✓	1	-	Spacer	-
[illegible] ✓	1	G	Pin	-
34000302 ✓	1	B	Spacer, Bearing, Lower	-
34000303 ✓	1	F	Rod	-
34000305 ✓	1	C	Spacer, Bearing, Upper *latest available*	-
34000306 ✓	1	E	Cover Assy	-
EO ✓		F		
34000308 ✓	1	B	Piston, Pneu.	-
34000309 ✓	1	D	Piston, Hyd.	-
EO ✓		E		
34000312 ✓	1	B	Cap, Hyd.	-
34000313 ✓	1	A	Shim, Bearing	-
34000314 ✓	1	-	Shim, Hyd. Cap	-
EO ✓		A		
34000315 ✓	1	-	Shim, Pneu. Cap	-
EO ✓		A		
34000316 ✓	1	D	[illegible] *latest available*	-
34000317 ✓	1	D	Pin, Sequence Valve	-
34[illegible]318 X	1	C	Follower Assy	-
[illegible] ✓	1	D	Sleeve	-
34000[illegible]3 X	1	-	Gasket, Tube	-
34000344 ✓	1	B	Cap, Pneu.	-
34000345 ✓	1	B	Plate, Torque Motor	-
34000346 X	1	B	Spacer Assy, Torque Motor	-

A Added D Deleted R Revised

LIST	Hydraulic Research Valencia, Calif.	Contract No. NAS 8-27980	Code Ident. 81873	DL 34000550	Revision Ltr A Date

DRAULIC ACTUATION SYSTEM, SSME — Authentication — Sheet 9 of 16 Sheets

Document Number	Sheet No.	Rev Ltr	Nomenclature Or Description	Chg Code
34000317 ✓	1	D	Support, Inlet Filter	-
34000318 ✓	1	A	Foot, RVDT	-
34000351 ✓	1	B	Piston & Rod Assy	-
34000352 ✓	1	B	Piston & Rod Assy	-
34000360 ✓	1	C	Fitting	-
34000361 ✓	1	-	Spacer	-
34000362 ✓	1	B	Retainer	
34000363 ✓	1	A	Washer, Tube	-
34000364 ✓	1	-	End Plug	-
34000372 ✓	1	-	Pin	-
34000373 ✓	1	B	Rod	-
34000374 ✓	1	B	Piston & Rod Assy	-
34000393 ✓	1	D	Stand Off	-
34000394 ✓	1	D	Pin *latest available*	-
34000395 ✓	1	B	Roller	-
34000396 ✓	1	C	Crank	-
34000397 ✓	1	E	Crank	-
34000398 ✓	1	-	Screw, Cap	-
34000402 ✓	1	C	Rod	-
34000403 ✓	1	D	Piston & Rod Assy	-
34000420 ✓	2	G	Actuator Assy, Pre[illegible]ner Valve	-
EO ✓		H		
34000430 ✓	2	F	Actuator Assy, Mai[illegible] ropellant Valve	-
EO ✓		G		
34000435 ✓	1	-	Ball	-
34000436 ✓	1	-	Pin	
34000437 ✓	1	A	Drive Bar, RVDT	

Change: A Added   D Deleted   R Revised

[illegible]	Contract No. NAS 8-27980	Code Ident. 81873	DL 34000550	Revision AE Ltr Date 12-20-76

[illegible] ACTUATION SYSTEM, SSME — Authentication — Sheet 10 of 16 Sheets

Chg	Document Number	Sheet No.	Rev Ltr	Nomenclature Or Description	Chg Code
	[illegible] ✓	2	E	Actuator Assy, Chamber Coolant Valve	-
	[illegible]		F		
	[illegible] ✓	3	G	Housing Assy	R
	[illegible] ✓	1	-	Pin Assy	-
	[illegible] ✓	1	B	Pivot	-
C	[illegible] ✓	1	A	Pin	-
	EO		B		
	[illegible] ✓	1	A	Pin	-
	[illegible] ✓		B		
	[illegible] ✓	3	C	Housing Assy	-
	[illegible] ✓		D		
	[illegible] ✓		E		
	[illegible] ✓	3	H	Housing Assy	R
	[illegible] ✓	3	E	Housing Assy	R
	✓	1	-	Plug, Bleed	-
	✓	1	A	Plate, Adapter	-
			D		
	✓	1	-	Insert	-
	✓	1	-	Insert	-
	✓	2	-	Housing, Formed	-
	✓	2	A	Housing, Formed	-
	✓	3	-	Housing Assembly	-
	✓	3	B	Housing Assembly	R

D Deleted   R Revised

LIST Hydraulic Research, Valencia, Calif. — Contract No. NAS 8-27500 — Code Ident. 81573 — D[illegible]

[illegible]
[HY]DRAULIC ACTUATION SYSTEM, [illegible]

	Document Number	Sheet No.	Rev Ltr	Nomenclature Or Description
[illegible]	340[illegible]	3	-	[illegible] Assembly
C	3[illegible]001152	1	-	Pin
	EO		A	
	EO		D	
	EO		C	
C	34001153	1	-	Pin
	EO		A	
	EO		B	
	EO		C	
C	34001025	1	A	Cap, Pneu. Latest available
C	34001026	1	-	Piston, Pneu.
D	34001027	1	-	Cylinder, Assy, Pneu.
[illegible]	34002020	3	F	Actuator Assy, [illegible] Valve
	EO		G	
[illegible]	34002030	2	E	Actuator Assy, Main Propellant Valve
[illegible]	34002040	2	E	Actuator Assy, Chamber Coolant Valve
C	41003495	1	-	Retainer
C	41003496	1	-	Spacer, Bearing, Upper
D	41003502	1	-	Pin
D	41003503	1	-	Pin
D	48001502	1	-	Frame Grind Assy
D	48001503	1	A	Housing Assy
[illegible]	48001504	1	-	Housing, Machined
E	48001505	1	A	Housing
C	48001506	1	A	Flexure Tube
D	48001507	1	A	Flapper
C	48001508	1	A	Armature

[illegible] A Added D Deleted R Revised

LIST Hydraulic Research, Valencia, Calif. — Contract No. NAS 8-27500 — Code Ident. [illegible] — DI[illegible]

[illegible]
[HYDR]AULIC ACTUATION SYSTEM, [illegible]

	Document Number	Sheet No.	Rev Ltr	Nomenclature Or Description
	48001[illegible]	1	A	[illegible]
	48001512	1	D	[illegible]
	48001513	1	A	Frame, [illegible] Casting
	48001514	1	B	Frame, Upper
	48001515	1	A	Frame, Upper, Casting
	48001516	1	-	Poppet and Seat Assy
	48001517	1	A	Magnet
	48001518	1	C	End Cap
	48001519	1	A	Seat
	48001521	1	-	Spacer
	48001522	1	A	Poppet
	48001523	1	-	Shim
	48001524	1	B	Cover
	48001525	1	-	Cover Casting
	48001527	1	A	Coil Assembly
	48001528	1	A	Coil Form
	48001529	1	B	Shipping Cover
	48002200	2	B	Torque Motor, Pilot Valve

[illegible] A Added D Deleted R Revised

[illegible], Calif.		Contract No. NAS 8-27980		Code Ident. 81873	DL 34000550	Rev Ltr	AE
						Date	[illegible]-20-76
Title [illegible] ACTUATION SYSTEM, SSME.				Authentication		Sheet [illegible] of [illegible]	Sheets

Size Code	Document Number	Sheet No.	Rev Ltr	Nomenclature Or Description	Chg Code
A	[illegible]	1	-	Drive Screw	-
C	[illegible]	1	B	Bolt, Tension, 12 Pt Ext Wrenching, 1200F	-
A	[illegible]	8	R	Packing, Preformed (0 ring)	-
[illegible]	[illegible]	1	S	Tube Assembly, Servovalve	R
J	[illegible]	1	L	Tube Assembly - Torque Motor	-
[illegible]	[illegible]	1	K	Transducer - Rotary	-
C	[illegible]	1	A	Filter Disc Assy	-
[illegible]	[illegible]	1	D	Pin Plug	-
D	[illegible]	1	C	Bearing	-
C	34000183	1	C	Cap Screw	-
C	34000184	1	C	Bearing, Self Aligning	-
D	34000188	1	-	Pin Plug	-
D	34000190	1	K	Tube Assembly - RVDT	-
B	34000191	1	B	Clamp Loop	-
E	[illegible]	1	D	Tube Assembly	R
C	[illegible]	1	A	Filter Assembly	-
D	[illegible]	1	A	Tube Assy, RVDT	-
D	[illegible]	1	A	Transducer, Rotary	R
		PARTS	LISTS		
[illegible] A	10[illegible] P/L	10	F	Parts List, Dual Redundant Rotary	-
[illegible]	PL[illegible]-11[illegible]	1	C	Filter Assy, Inline	-
[illegible]	[illegible]	4	D	Servoswitch Assembly	-
[illegible]	[illegible]	5	H	Servovalve Assembly	-
[illegible]	[illegible]	8	G	Actuator Assembly, Preburner Valve	-
	[illegible]		H		
[illegible]	[illegible]	8	F	Actuator Assembly, Main Propellant Valve	-
	[illegible]		G		

[illegible] Change: A Added D Deleted R Revised

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ITEM I
POWER SYSTEM

SPACE SHUTTLE DATA
ORBITER HYDRAULIC SUBSYSTEM

Sheet 1 of 4 1

SPECIFICATION NUMBER		COMPONENT	SUPPLIER	PART NUMBER		ASSEMBLY NUMBER		PARTS LIST		LIST OF MATERIAL		REMARKS
MC201-0029-0002	D	Pump Inst Var. Disp	Abex			65111-02	-		-		-	
"	/	Pump Assy Var. Disp	Abex			65311-02	N		N		N	
MC282-0062-0002	3	Reservoir Assy	Arkwin			1711012-002	A		-		-	
"	/	Relief Valve Assy	Arkwin			1711012-200	-		*		/	
"	/	Fluid Quan Indic. Assy	Arkwin			1711012-101	G		*		/	
"	/	Bleed and Sampling Valve	Arkwin			1711012-103	B		*		/	
ME449-0177-6103	D	Press. Transducer	Statham			PA8102-250-19948 P/N Dwg 58969	-		-		-	Used with reservoir
ME449-0156-0002	C	Temp. Transducer	Rosemount	134MW	A				N		/	Used with reservoir Also SSME Control S/O V.
MC621-0026-0002	G	Filter Module Assembly	Purolator			7583886	A		*		*	
"	/	Supply Filter Element	Purolator			7583887	-		*		/	
"	/	Return Filter Element	Purolator			7583888	-		N		N	
"	/	Case Drain Filter Element	Purolator			7581280	-		*		*	
"	/	Supply Relief Valve	Purolator			7581310	E		*		/	
"	/	Diff. Pressure Indicator	Purolator			7581272	D		*		/	
"	/	Manifold Assy	Purolator			7583893	-		-		N	
"	/	Case, Case Drain	Purolator	7581271	A				*		*	
"	/	Case, Return	Purolator	7581469	C				*		*	
"	/	Case, Supply	Purolator	7581270	F				*		*	
ME449-0177-6105	/	Press. Transducer	Statham			PA8103-4M-20320 P/N 58969 Dwg	N				N	Used with filter module
ME271-0079-1001	E	Hose Assembly	Titeflex			106056-1001	D		-		-	
ME284-0434-2020	C	Check Valve	Crissair			4C3032-2	F		*		-	
MC621-0035-0005	B	Accumulator Assy	Parker			5740015-103	G		-		-	
"	/	Relief Valve	Parker			2741548	D		*		/	Used with accumulator
"	/	GN_2 Press. Gage	Parker (Glassco)			2741570	C		*		*	Used with accumulator
"	/	Fill Valve	Parker			2741546	C		*		*	Used with accumulator
	/	Reservoir Inst.	R.I.			V070-585063	-		-		/	

POWER SYSTEM I

SPACE SHUTTLE DATA

ORBITER HYDRAULIC SUBSYSTEM

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SPECIFICATION NUMBER		COMPONENT	SUPPLIER	PART NUMBER		ASSEMBLY NUMBER		PARTS LIST		LIST OF MATERIAL		REMARKS
MC284-0417-0001	B	Accum. Press. Priority Valve	Pneudraulics			4600	H		—		—	
"	/	End Cap	Pneudraulics	45207	-				*		*	
"	/	Adapter	Pneudraulics	45211	-				*		*	
"	/	Body	Pneudraulics	45215	D				*		*	
"	/	Poppet	Pneudraulics	45214	A				*		*	
MC621-0034-0001	B	Manual Dump Valve	Whittaker	149975	F	149974	E		*		-	
MC284-0430-0002	B	Press. Act. Contr. Valve	Arkwin			0411069-001	D		*		N	
MC621-0018-0001	D	Circulation Motor-Pump Outline	Pneu. Devices			2166	T		/		/	
"	/	Circulation Motor-Pump Assy	Pneu. Devices			11926	C		-		-	
"	/	Subassy Housing Inverter	Pneu. Devices			11927	D		*		*	
"	/	Subassy Housing Pump	Pneu. Devices			11929	B		*		N	
"	/	Valve, Relief, Bypass	Pneu. Devices			12200	C		N		N	SCD, see Page 3
"	/	Dual Pump Assy	Pneu. Devices			11939	H		*		N	
MC284-0412-0002	C	Thermal Contr. Valve	Pneudraulics			9402	F ∅		—		—	∅ Drawing illegible
"	/	Valve Detail	Pneudraulics	92042	B	*	*		*		*	
"	/	Valve Detail	Pneudraulics	92041	A	*	*		*		*	
MC250-0001-0075	C	Oil/Freon Heat Exch.	Ham Standard			SV729780	B		*		*	
MC250-0019-0011	/	Water Spray Boiler	Ham Standard			SV766514-1	H		—		—	
"	/	Hyd Bypass and Relief Valve	Ham Standard			SV766502	-		N		N	Part of water spray boiler
"	/	Water Spray Boiler Install Dwg.	" "			SVHS 766500	B		/		/	Not Requested
MC621-0024-0200	B	Ground Serv. Quick Disc.	Symmetrics			501200	N		-		-	See Dwg. 501150
MC621-0024-0600	/	"	"			50/600	N		-		-	See Dwg. 501550

NOTES: * = Data is a part of the drawing.

A, B, C, etc. = Change letter of document in our files

(- = No change)

N = This document is needed.

SPACE SHUTTLE DATA

POWER SYSTEM

SPECIFICATION NUMBER		COMPONENT	SUPPLIER	PART NUMBER		ASSEMBLY NUMBER	PARTS LIST	LIST OF MATERIAL		REMARKS
MC-284-0438-0002	/	Housing Assy	Arkwin			0411069-102	N		N	Part of Press Act Contr Valve
"	/	Pilot Valve Assy	Arkwin			0411069-103	N		N	"
"	/	Spacer	Arkwin	0411069-204	N				N	"
"	/	Spring	Arkwin	0411069-208	N				N	"
"	/	Spring	Arkwin	11A014-26	A				N	SCD to pneu. devices P/N 12200
MC621-0018	d	Rel. Valve	Pneudraulics		/	1791	N	/	-	
MC621-0035-0006	B	Accumulator	Parker-Hannafin		/	2751508	-	-	N	
"	/	Accumulator Fill Valve	Parker-Hannafin		/	2741546	N	/	-	See File I-1
ME449-0177-6101	/	Accumulator Press Gage	Statham		/	PA8103-4M-19946 P/N 58969 Dwg.	-	-	N	
MC621-0035-	/	Accumulator Relief Valve	Parker-Hannafin		/	2741548	N	/	-	
MC-621-0024-0300	/	Quick Disc. Hydraulic	Symetrics			501300	N	/	-	See Dwg 501350
MC-621-0024-2400	/	"	"			501400	N	/	-	
MC-621-0024-0500	/	"	"			501500	N	/	-	See Dwg 501750
MC-621-0024-0700	/	"	"			501700	L	/	-	
MC-621-0024-0800	/	"	"			501800	N	*	*	Not requested
ME354-0013-0001	/	Insulation APU Service Panel	Hi-Temp Insul.			59H1040	L	*	*	
MC250-0001-0015	E	Heat Exch. Hydraulics	Ham Standard			SV729780	B	*	*	Not requested
	/	Heater Inst Sta. 1307	R.I.			V070-585061	-	*	*	
MC282-0062-0102	D	Poppet	Arkwin	1711012-270	A			*	*	Part of reservoir relief valve
"	/	Piston	Arkwin	1711012-269	A			*	*	
"	/	Retainer	Arkwin	1711012-138	-			*	*	Part of accumulator assembly
MC621-0035-0005	B	Accumulator	Parker Hannifin	2751508	N			*	*	Part of thermal control valve
MC284-0412-0002	/	Thermal Element	Pneudraulics			92046	N	*	*	Part of freon heat exchanger
MC250-0001-0015	E	Core Heat Exchanger	Ham Standard			SV764177-1	D			

SPACE SHUTTLE DATA

POWER SYSTEM

SPECIFICATION NUMBER		COMPONENT	SUPPLIER	PART NUMBER		ASSEMBLY NUMBER	PARTS LIST	LIST OF MATERIAL		REMARKS
MC250-0019-0001	B	Boiler, Spray	Ham Standard			SV766503-1	-	*	*	
"	/	Housing, Valve	Ham Standard	SV761780-1	N			*	*	
"	/	Housing Valve	Ham Standard	SV766535-1	N			*	*	
"	/	Spool, Valve	Ham Standard	SV761694-1	N			*	*	
"	/	Poppet, Valve	Ham Standard	SV764105-1	N			*	*	Part of water spray boiler
"	/	Cover, Valve	Ham Standard	SV766538-1	N			*	*	
"	/	Seat, Spring, Small	Ham Standard	SV764098-1	N			*	*	
"	/	Sensor, Temp	Ham Standard	SV755529-8	L			*	*	
MC621-0026-0002		Housing	Purolator	7581331	H			*	*	
MC282-0062-0002	D	Assembly Reservoir	Arkwin			1711012-030		/	*	
"	/	Cylinder	Arkwin	1711012-202				/	*	
"	/	Cylinder Bootstrap	Arkwin	1711012-232	F			/	*	
"	/	Piston Bootstrap	Arkwin	1711012-233	C			/	*	
"	/	Bleed Tube Inner	Arkwin	1711012-235	A			/	*	Part of reservoir assembly
"	/	Guide	Arkwin	1711012-238	-			/	*	
"	/	Bleed Tube Outer	Arkwin	1711012-237	-			/	*	
"	/	Spindle	Arkwin	1711012-239	A			/	*	
"	/	Tube End	Arkwin	1711012-236	-			/	*	
"	/	Piston Main	Arkwin	1711012-241	C			/	*	
"	/	Cover Fluid, Casting	Arkwin	1711012-301	B			/	*	

ITEM II
MAIN ENGINE GIMBAL ACTUATION

SPACE SHUTTLE DATA
ORBITER HYDRAULIC SUBSYSTEM

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SPECIFICATION NUMBER		COMPONENT	SUPPLIER	PART NUMBER		ASSEMBLY NUMBER		PARTS LIST		LIST OF MATERIAL		REMARKS
						2741546						
MC284-0469-0001	C	Valve Assy	Wright Components		/	15846	A		*		*	
MC621-0024-0100	/	Quick Disconnect	Symmetrics, Inc.		/	501100	N		-		-	See typ dwg -0100 Item I Pg 2.
MC621-0024-0600	/	Quick Disconnect	Symmetrics, Inc.		/	501600	/		-		-	(Item I Pg 2)
ME449-0043-0007	P	Diff. Press. Transducer	Gulton Ind. Corp.		/		N		N		N	
MC277-0002-1013	C	Hose and Swivel Assy	Titeflex		/	106080-1013	G		*		*	
MC621-0046-0004	E	Shutoff Valve	Sterer		/	54070-3	D		/		N	
ME284-0434-1020	B	Check Valve	Crissair		/	4C3020	L		*		L	
ME284-0434-2012	/	Check Valve	Crissair		/	4C3028-2	L		*		*	
ME449-0177-0107	/	Pressure Transducer	Statham		/	PA8102-400-20703 PN Dwg 58069	-		-		-	See File I-1
ME449-0156-0003	B	Temperature Transducer	Rosemount		/	134NM	N		N		N	Same as unit on reservoir
-	/	Manifold	R.I.			V070-585328-001	N		/		N	

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SPECIFICATION NUMBER		COMPONENT	SUPPLIER	PART NUMBER		ASSEMBLY NUMBER		PARTS LIST		LIST OF MATERIAL		REMARKS
MC621-0015-0004	B	Servoactuator Assy Model 17-325	Moog			A23763	-		*		*	
•	/	Servoactuator Assy Model 16-174	Moog			A24024	-		*		*	DUPL
•	/	Power Valve Assy Model 33-215	Moog			A23767	-		*		*	DUPL
•	/	Position Feedback Assy	Moog			A07187	B		*		*	
•	/	Power Valve Assy Model 33-216	Moog			A23853	-		*		*	
•	/	Power Valve Assy Model 33-217	Moog			A23854	-		*		*	DUPL
•	/	Servovalve Assy Model 16-175	Moog			A24026	-		*		*	DUPL
•	/	Servovalve Assy Model 16-177	Moog			A24202	-		*		*	DUPL
•	/	Piston Assembly	Moog			A24196	-		*		*	DUPL
•	/	Elec. Schematic	Moog			A23825	-		*		*	DUPL
•	/	Cyl. & Bearing Assy	Moog			A23715	C		*		*	DUPL
•	/	Servo Actuator Assy SSME/TVC	RI			V070-585503	-		*		*	Made from 17-325
•	/	Orifice	Moog	A05105	D				*		*	
•	/	Spool, Isolation Valve	Moog	A05311	A				*		*	
•	/	Bushing, Isolation Valve	Moog	A05312	A				*		*	
•	/	Feedback Cage Assy	Moog			A05373	B		*		*	
•	/	Filter	Moog	A05716	A				*		*	
•	/	Spring, Comp Helical	Moog	A05769	A				*		*	
•	/	Sleeve, Selector and Lock Valve	Moog	A05869	A				*		*	
•	/	Arm, Upper, Feedback	Moog	A07185	A				*		*	
•	/	Arm, Lower, Feedback	Moog	A07186	A				*		*	
•	/	Link, Feedback	Moog	A07233	B				*		*	
•	/	Trans. Assy, Position	Moog			A07553	A		*		*	
•	/	Conduit & Fitting Assy Selector Valve No. 1	Moog			A07881	-		*		*	
•	/	Valve, Check	Moog			A20950	A		*		*	
•	/	Servoactuator Instl	Moog	A23760	-				*		*	

MAIN ENGINE GIMBAL ACTUATION

SPECIFICATION NUMBER		COMPONENT	SUPPLIER	PART NUMBER		ASSEMBLY NUMBER		PARTS LIST	LIST OF MATERIAL		REMARKS
MC621-0015-0004	/	Hyd. Schematic	Moog	A23764	-				/	*	
•	/	Body Assy	Moog			A23765	-		*	/	
•	/	Cylinder and Bearing Assy	Moog			A23473	B		*	/	
•	/	Diff. Press Indicator	Moog	A23369	B				*	*	
•	/	Piston Assy	Moog			A24192	N		N	/	
•	/	Cam Support & Insert Assy	Moog			131-78412	B		*	/	
•	/	Cam & Inner Race Assy	Moog			A24171	-		*	/	
•	/	SSSSA-Selector Valve 1	Moog			A23419	-		*	/	
•	/	Bushing	Moog	A23417	-				/	*	
•	/	Spool	Moog	A23418	-				/	*	
•	/	Trans. LVDT	Moog			A24211	N		N	/	
•	/	BSSA Lock Valve Assy	Moog			A23409	A		*	/	
•	/	Force Limiter Assy	Moog			A23766	-		*	/	
•	/	Bushing & Spool Assy	Moog			A23524	-		*	/	
•	/	Bushing	Moog	A23522	-				/	*	
•	/	Spool	Moog	A23523	-				/	*	
•	/	Union	Moog	A23797	-				/	*	
•	/	Union	Moog	A23798	N				/	*	
•	/	Union	Moog	A23796	-				/	*	
•	/	Tail Stock & Bearing Assy	Moog			033-79876	B		*	/	
•	/	Housing & Bushing Assy	Moog	A23852 (Unreleased)	N				/	N	
•	/	Housing Assy	Moog			A23547	-		*	/	
•	/	Dyn Press Feedback Assy	Moog			A23900	-		*	/	
•	/	Diff Press Trans Assy	Moog			A24010	-		*	/	
•	/	Cage, Feedback	Moog	A05356	E				/	*	
•	/	Nozzle Body	Moog	070-06765	N				/	N	Contractually Not Available (Confid. Design)

SPACE SHUTTLE DATA

MAIN ENGINE GIMBAL ACTUATION

SPECIFICATION NUMBER		COMPONENT	SUPPLIER	PART NUMBER		ASSEMBLY NUMBER		PARTS LIST		LIST OF MATERIAL		REMARKS
MC621-0015-0004	/	Nozzle Tip	Moog	070-06766	/				/		/	Contractually Not Available (confidential Design)
"	/	Nozzle Assy	Moog			070-07549	V		*		/	070-06765 Body, 070-06766 Tip } Info. only
"	/	Cylinder	Moog	A23473	N				/		N	
"	/	Piston	Moog	A23600	-				/		*	
"	/	Union	Moog	A20888	N				/		N	See III Sheet 2
"	/	Union	Moog	073-63836	D				/		*	
"	/	Spring Compression	Moog	A07188	N				/		N	
MC-364-0011	/	INSULATION BLANKET	HI-TEMP			59M 1012	-		*		-	
MC621-0015-0004	/	Piston	Moog	A23545	-				/		*	
"	/	Power Valve Assy	Moog			A23767	-		*		*	
"	/	Body Assy Servo Valve	Moog			A23219	N		*		*	
"	/	Body	Moog	A24055	N				*		*	This is a sub of A23219 above

NOTES: * = Data is a part of the drawing.

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ITEM III

ELEVON ACTUATION SYSTEM

SPACE SHUTTLE DATA
ORBITER HYDRAULIC SUBSYSTEM

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III

SPECIFICATION NUMBER		COMPONENT	SUPPLIER	PART NUMBER		ASSEMBLY NUMBER		PARTS LIST		LIST OF MATERIAL		REMARKS
ML621-0014-0007	E	Servoactuator Assy Inboard Model 17-316	Moog			A20637	-		*		/	
"	/	Servoactuator Instl	Moog			A20556	B		*		/	
"	/	List of Materials	Moog			A20560	D		*		/	
"	/	Hydraulic Schematic	Moog			A20537	D		*		/	
"	/	Power Valve Assy Model 33-213	Moog			A20569	B		*		/	
"	/	Cyl & Gland Assy	Moog			A20845	B		*		/	
"	/	Piston Assembly	Moog			A20703	B		*		/	
"	/	Body Assembly	Moog			A20696	-		*		/	
"	/	Servo Valve Assy Model 16-173	Moog			A20568	-		*		/	
"	/	Connector, Rcpt Electrical	Moog	A05122	D				/		*	Not legible
"	/	Solenoid Valve Assy	Moog			A05745	F		*		/	
"	/	Pressure Indicator Filter Differential	Moog			A05755	F		*		/	Not legible
"	/	Plug, Pin Short Modified	Moog	A07110	A				/		*	
"	/	Valve, Flow Cutoff	Moog	A07712	A				/		*	
"	/	Retainer, Threaded Pin Plug	Moog	A20422	A				/		*	Not legible
"	/	Ring, Piston Rod Assy	Moog			A20547	-		*		/	
"	/	Union .625 Dia Passage	Moog	A20552	-				/		*	
"	/	List of Materials Servoactuator, Outbd	Moog			A20561	C		*		/	Not legible
"	/	Seal, Cap, O-Ring Piston	Moog	A20562	A				/		*	
"	/	Bushing, Spool and Sleeve Assy Sel Valve 1	Moog			A20563	A		*		/	
"	/	Quad Linear Trans. Inboard	Moog	A20630	B				/		*	Not legible
"	/	Filter	Moog	A20631	-				/		*	
"	/	Tailstock, Inboard	Moog	A20697	A				/		*	
"	/	Thermal, Jacket Inbd	Moog			A20702	A		*		/	Not legible
"	/	Piston Assy Inboard	Moog			A20703	B		*		/	
"	/	Rod End Inboard	Moog	A20705	A				/		*	

SPACE SHUTTLE DATA

ELEVON ACTUATION SYSTEM

SPECIFICATION NUMBER		COMPONENT	SUPPLIER	PART NUMBER		ASSEMBLY NUMBER		PARTS LIST		LIST OF MATERIAL		REMARKS
[illegible]-0014-C037	/	Fork, Anti-Rotation Inboard	Moog	A20707	-				/		*	
•	/	Ring, Wear	Moog	A20711	-				/		*	
•	/	Adjuster Assembly	Moog			A20823	A		*		/	
•	/	Housing & Bushing Assy Power Valve	Moog			A20835	B		*		/	
•	/	Tailstock & Bearing Assy	Moog			A20875	-		*		/	
•	/	Rod End & Bearing Assy	Moog			A20876	-		*		/	
•	/	Plug, O-Ring	Moog	A20883	-				/		*	
•	/	Retainer, Threaded Inbd	Moog	A20884	-				/		*	
•	/	Union .250 Dia Passage	Moog	A20888	-				/		*	
•	/	Seal, Face	Moog	A20890	B				/		*	
•	/	Nut, Spanner	Moog	A20891	B				/		*	
•	/	Seal, Low Friction Internal Groove	Moog	A20956	-				/		*	
•	/	Bushing, Spool & Sleeve Assy Sel. Valve 2	Moog			A20961	-		*		/	
•	/	Valve, Flow Cutoff	Moog	A20969	-				/		*	
•	/	Packing	Moog	A21160	-				/		*	Not legible
•	/	Seal, Barrier	Moog	A23173	A				/		*	
•	/	Seal, External Groove	Moog	A23189	-				/		*	
•	/	Wiring Schematic	Moog	A20878	N				/		/	(Unreleased)
•	/	Ring, Scraper	Moog	131-09084	C				/		*	
•	/	Nozzle Assy	Moog			070-07549	N		N	NOTES: * = Data is a	/	part of the drawing.
•	/	Orifice Assy	Moog			A07764	-	A07763 Body 071-22286-3 Orifice		A, B, C, etc.	=	Change letter of document in our files
•	/	Bushing & Spool Assy	Moog			A05364	C				/	(- = No change)
•	/	Envelope	Moog	A20882 (Obsolete)	/				/	N = This docu	/	ment is needed.
•	/	Hyd. Schematic	Moog	A20537	-				/		*	
•	/	Pin Plug	Moog	093-78638	A				/		*	
		Hyd System Inst Elevon	R.I.			V070-586070	-		*		*	

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Elevon

SPACE SHUTTLE DATA
ORBITER HYDRAULIC SUBSYSTEM

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A20540	A	A07664	A	072-79239	-	A20621	
A20558	A	A07665	A	A05786	-	A20622	
A20630		A07666	A	A20948		072-45333	-
131-09004		A07667	A	A20871	B	060-45620	
A20956		A07668	A	A20203	-	072-07531	F
A21160	A	A20570	D	A20504	-	072-20939	
A20624	-	A20966	B	A21210	-	072-64425	A
A20633	B	A20967	B	130-98561	A	082-67997	A
A20335	-	A05319	B	071-98563	-	A20565	A
A20886	-	A21267	-	A21197	-	A20634	-
A20331	A	A05315	C	062-98598	B	A05105	
073-70438	A	A05314	C	111-64646	A	023-33676	
093-78638		A05316	A	111-98564	-	A20990	
A20422	A	A05313	B	111-98565	-	A20332	
A20824		A05317	C	094-7992	-	A20533	A
A20627	A	A05318	B	110-98562	C	A20953	
A20628	-	110-78686	-	043-98569	A	A20715	-
A20552		A05537	-	091-98570	A	A20962	-
A20890		095-58322	C	082-74415	A	A20963	B
A20388		A05312		A20205	-	A05869	
A05746	A	A05311		A21196	-	A20826	-
110-79918	C	111-59635	B	A20567	-	A20827	-
111-79917	B	111-59633		A20874	-	A20835	
111-33975	B	A07720	-	A20954	-	A05364	
091-74326	C	A05744	B	A20955	-	A05745	
082-45200	A	071-65262	B	052-79267	B	A20631	
A07905	A	071-50212	A	A05330	B	A20840	A
092-63628	-	071-46672	C	093-79268	A	A05333	-
A05211	E	071-46637	B	070-07549		A20843	-
A07878	-	071-65261	C	A07764		072-20939	
091-79287	A	072-46645	D	071-25035	C	072-98086	-
A05545	A	072-46652	H	071-69749	-	A20701	
A21156	-	072-46689	D	072-24483		023-63676	E
A05929	A	070-46661	A	070-44105		A20968	A
A07662	B	A07320		A20623	-	A23189	

ITEM III
Elevon

SPACE SHUTTLE DATA
ORBITER HYDRAULIC SUBSYSTEM

Rev. 7/21/78
Sheet 4 of 4

A20950	
A20712	-
A20561	
A05755	
A20422	
A24012	-
A24013	-
A24014	-
A24015	-
A23171	A
A23347	A
A23348	B
A23194	B
A20204	-
A20536	D
A20937	B
A20872	-

ITEM IY

SPACE SHUTTLE DATA

RUDDER/SPEEDBRAKE

ORBITER HYDRAULIC SUBSYSTEM

Rev. 7/21/78

SPECIFICATION NUMBER		COMPONENT	SUPPLIER	PART NUMBER		ASSEMBLY NUMBER		PARTS LIST		LIST OF MATERIAL		REMARKS
MC621-0053-0001	D	Hyd Valve Module Assy Model 10-156	Moog			A23830	-		*		/	
"	/	Switching Valve Module Assy Model 50-467	Moog			A24190	-		*		/	
"	/	Body & Bushing Assy Triplex Power Valve	Moog			A24149	-		*		/	
"	/	Power Valve Assy Model 33-213	Moog			A24150	-		*		/	
"	/	Servo Valve Assy Model 16-178	Moog			A24066	A		*		/	
"	/	Hyd Valve Module Hyd Schematic	Moog			A24188	-		*		/	
"	/	Body Assy	Moog			A24023	N		N		/	
	/	Bushing & Spool Assy	Moog			A24080	N		N		/	
"	/	Bushing & Spool Assy	Moog			A24147	-		N		/	
"	/	Drive Arm Assy	Moog			A24108	N		N		/	
"	/	Clamp, Drive Arm	Moog	A24062 (Unreleased)	N	63278			/		N	
"	/	Screw	Moog	A24064	N	500139			/		N	
"	/	Bushing, Spool & Sleeve Assy	Moog			A23925	N		N		/	
"	/	Manifold Assy	Moog			A24073	N		N		/	
"	/	Hydraulic Motor	Abex			63078-02	N		N		/	
"	/	Pressure Actuated Brake	Sundstrand			5001139	Y		N		N	
"	/						/		/		/	
"	/	Control Module & Hyd Motor	Sundstrand			5001078	J		*		*	
MC285-0076-0001	A	Oleophobic Filter	Arkwin			0711325-106	-			NOTES: * = Data is a	part of the drawing.	
	/	Flexible Hose	R.I.			V070-585406-002	A		/	A, B, C, etc. =	Change letter of document in our files.	
	/	Shaft Seal Drain Manifold	R.I.			V070-587104	-		/		(- = No change)	
	/	Overboard Drain	R.I.			V070-587105	-		/	N = This docu	ment is needed.	
MC621-0053-0001	/	Rudder/ Speedbrake Inst	R.I.			V070-577001	-		*		/	
		Hyd System R/SB OV-102	R.I.			V070-587303	-		/		/	
		Hyd Lines Inst Vert Stab	R.I.			V070-587006	-		*		/	Not requested

ITEM IV
RUDDER/SPEEDBRAKE

SPACE SHUTTLE DATA

IV

SPECIFICATION NUMBER		COMPONENT	SUPPLIER	PART NUMBER		ASSEMBLY NUMBER		PARTS LIST		LIST OF MATERIAL		REMARKS
MC621-0053-0001	/	Union	Moog	A23797	N				*		*	
"	/	Union	Moog	A24232	N				*		*	
"	/	Union	Moog	A24233	N				*		*	
"	/	Body Assy Servo Valve	Moog			A24297	"		*		*	
"	/	Body	Moog	A24023	N				*			This is a sub of A24297 above
"	/		Moog	24149	N							Component (title) unknown

RUDDER/SPEEDBRAKE

MOOG DRAWINGS:

DRAWING NUMBER	TITLE
L-2037	Layout-Hydraulic Fittings & Electrical Connectors, Rudder/Speedbrake
072J01379	Bottom Polepiece Blank
080-04273	"O" Ring
A05105	Orifice
A05122	Connector, Rcpt., Electrical
A05311	Spool, Isolation Valve
A05312	Bushing, Isolation Valve
A05313	End Bushing - Power Valve
A05314	Drive Piston Power Spool
A05315	Sleeve, Intermediate Power Spool
A05316	Sleeve-End Power Spool
A05317	Closure Stop, Power Spool
A05318	Retainer, Threaded Power Spool
A05330	End Cap
A05333	End Cap and Pin Assy
A05337	Nut, Self Locking, Hexagon
A05364	Bushing & Spool Assy-Fitted
A05537	Pin, Index - Power Valve Bushing
A05744	Housing, Solenoid Valve - Power Manifold Assy
A05745	Solenoid Valve Assembly
A05755-1	Pressure Indicator, Filter Differential
A05786	Cover, Solenoid

REQUEST THE FOLLOWING MOOG DRAWINGS: (CONT'D.)

DRAWING NUMBER	TITLE
A06005	Air Speed Output Assembly
092-06131	Washer
102-06892	Spacer, Plate-Motor
A07110	Plug, Pin, Short, Modified
A07327	Stop, Spool Power Valve
A07378	Shim
A07470	Washer, Tab Lock
072-07531	Magnet - Permanent
A07552	Lubricant, Grease
A07687	Body
A07720	Spring, Compression, Helical
A07820	Coil Assembly, Solenoid Valve
A07911	Body, Slotted
094-20120	Wire, Lock
A20400	Screw, Cap, SCH UNRC-3A
A20401	Screw, Cap, SCH UNRF-3A
A20871	Ring, Metallic Barrier
A20890	Seal, Face
072-20939	Polepiece, Bottom
A20965	Bushing, Spool and Sleeve Assembly
~~A20969~~	~~Valve, Flow Cut-Off~~
A20970	Transducer, LVDT
A21156	Seal, External Groove
A21160	Packing, Preformed, Hydraulic, +275°F (O-ring)

REQUEST THE FOLLOWING MOOG DRAWINGS: (CONT'D.)

DRAWING NUMBER	TITLE
A21229	Container, Shipping; Actuator
A21254	Pictorial Assembly (Hydraulic Amplifier Assy)
A21267	Pin, Dowel
A21561	Servovalve Assy - Model 30-263B
A21562	Servovalve Installation, Model 30-263B
A21650	Nameplate
A21662	Body & Orifice Assy Dynamic Pressure FDBK
A21759	Armature and Flow Guide Assembly
A21788	Seal, Internal Groove
A21797	Seal, Low Friction, External Groove
074-22059	Nameplate
A23063	End Cap
A23171	Transducer Assy Differential Pressure
A23189	Seal, External Groove
A23190	Seal, Internal Groove
A23191	Sleeve Diff Pressure Transducer
A23192	Sleeve, Flanged, Diff Pressure Transducer
A23193	Tube Diff Pressure Transducer
A23194	Tube, Sleeve & Piston Assy Diff Pressure Transducer
A23195	Spacer Diff Pressure Transducer
A23347	Housing Assy Diff Pressure Transducer
A23348	Tube Support Diff Pressure Transducer

REQUEST THE FOLLOWING MOOG DRAWINGS: (CONT'D.)

DRAWING NUMBER	TITLE
A23351	Filter
A23352	Flange, Clamping Diff Pressure Indicator
A23360	Retainer, Threaded Diff Pressure Transducer
A23361	Spring, Coned Disc (Belleville)
A23362	Washer, Anti-Rotation
A23364	End Cap
A23366	Seal External Groove
A23368	Solenoid Valve Assembly
A23741	Bracket Assembly
A23781	Body
A23797	Union Force Limiter to Actuator
A23830	Hydraulic Valve Module Assy Model 10-156
A23863	Bushing Switching Valve
A23881	Bushing Tandem Power Valve
A23882	Spool Tandem Power Valve
A23883	Drive Rod Tandem Power Valve
A23884	Closure Tandem Power Valve
A23885	Retainer, Threaded Tandem Power Valve
A23886	Shim, Closure Tandem Power Valve
A23887	Spool, Switching Valve
A23892	Shim, Drive Rod Tandem Power Valve
A23898	Body Assembly, Dynamic Pressure Feedback
A23899	Cap, Spring, Dynamic Pressure Feedback

REQUEST THE FOLLOWING MOOG DRAWINGS: (CONT'D.)

DRAWING NUMBER	TITLE
A23900	D.P.F. Assembly
A23901	Stop, Piston, Dynamic Pressure Feedback
A23919	Power Valve Assembly, Model 33-210A - S.R.B.
A23924	Sleeve, Switching Valve
A23925	Bushing, Spool and Sleeve Assembly Switching Valve
A23932	Sleeve, Clamping Switching Valve
A23933	Shim, Transducer
A23935	Housing, LVDT Switching Valve
A23939	Bushing, Pivot Switching Valve
A23940	Seat, Spring Switching Valve
A23941	Spring, Compression, Helical
A23942	Seat, Spring Switching Valve
A23947	End Cap Switching Valve
A23949	Retainer, Threaded Switching Valve
A24011	Transducer Assembly, Differential Pressure
A24012	Housing Assy Diff Pressure Transducer
A24013	Tube Support, Diff Pressure Transducer
A24014	Tube, Sleeve & Piston Assy Diff Pressure Transducer
A24015	Tube, Diff Pressure Transducer
A24016	Piston Diff Pressure Transducer
A24017	Sleeve Diff Pressure Transducer
A24018	Sleeve, Flanged Diff Pressure Transducer

REQUEST THE FOLLOWING MOOG DRAWINGS: (CONT'D.)

DRAWING NUMBER	TITLE
A24019	Spacer, Diff Pressure Transducer
A24023	Body Assembly Triplex Power Valve
A24063	Drive Arm Clamp Triplex Power Valve
A24064	Screw, Modified-Drive Arm Triplex Power Valve
A24065	Drive Rod Clamp Triplex Power Valve
A24066	Servovalve Assembly Model 16-178
A24067	Bushing Power Valve
A24068	Spool Power Valve
A24069	Bushing & Spool Assembly, Fitted
A24070	Bushing & Spool Assy Nulled
A24073	Manifold Assembly, Switching Valve
A24079	Bushing & Spool Assy Fitted
A24080	Bushing & Spool Assy Nulled
A24082	Drive Rod, Power Spool
A24108	Drive Arm Assembly Triplex Power Valve
A24123	Plate, Cover
A24124	Transducer LVDT
A24147	Bushing, Spool and Sleeve Assy
A24149	Body and Bushing Assy Triplex Power Valve
A24150	Power Valve Assy Model 33-218
A24170	Cover, Casting Power Valve
A24188	Hydraulic Valve Module Rudder/Speedbrake Hydraulic Schematic

ITEM IV
RUDDER/SPEEDBRAKE

Sheet 9 of 11

REQUEST THE FOLLOWING MOOG DRAWINGS: (CONT'D.)

DRAWING NUMBER	TITLE
A24190	Switching Valve Module Assembly Model 50-467
A24230	Cover, Machined Power Valve
A24234	Support, H.V.M.
A24290	Support Assy, H.V.M.
A24291	Bushing H.V.M. Support
073-26125	Cap, Vent
080-26133	Gasket, "O" Ring
092-26769	Washer, Lock, Spring
111-33975	Pivot-Valve
082-45200	Ring Backup Single Turn
071-46637	Filter, Downstream
110-46639	Spring, Compression, Plunger Return, Sol. Valve
102-46640	Spacer, Stroke, Solenoid Valve
064-46642	Guide, Plunger, Solenoid Valve
072-46645	Polepiece, Solenoid Valve
060-46646	Coil Form, Solenoid Valve
072-46652	Armature
070-46661	Ball, Solenoid
071-46672	Retainer, Filter
072-46689	Probe, Armature
102-46719	Shim, Spring Adjust.
102-46721	Damper, Coil
072-47659	Top Polepiece
073-26126	Spacer-Vent
071-24963	Filter
A24293	Washer, Bearing

ITEM IV
RUDDER/SPEEDBRAKE

Sheet 10 of 11

REQUEST THE FOLLOWING MOOG DRAWINGS: (CONT'D.)

DRAWING NUMBER	TITLE
095-49486	Sealing, Locking and Retaining Compounds Single Component
072-49864	Armature Assy
071-50212	Filter Disc Specification Control Dwg
091-50504	Nut, Self-Locking, Hexagon Low Height
111-59633	Spring Seat
111-59635	Spring Seat - Stop
094-60230	Insert, Cres. Helical Coil
102-64145	Shim, Cas Press. Reg.
111-64646	Pivot Cas. Actuator
071-65261	Orifice, Return, Solenoid Valve
071-65262	Orifice, Pressure, Solenoid Valve
020-65454	Pressure Orifice Assembly
071-69749	Retainer, Filter
073-70438	Fitting, Hydraulic
081-70460	Gasket, Solenoid Valve
090-70572	Screw, Machine Slotted Head, Drilled
082-74415	Retainer, Packing Backup
102-78307	Shim
093-78639	Plug, Pin, Short, Aluminum
110-78686	Spring, Coned Disc (Belleville)
121-78689	Rod Guide
082-79183	Retainer, Packing Backup
072-79239	Polepiece
073-70138	Fitting, Hydraulic

REQUEST THE FOLLOWING MOOG DRAWINGS: (CONT'D.)

DRAWING NUMBER	TITLE
052-79267	Stop, Spool
093-79268	Pin End Cap
091-79287	Retainer, Plug, Threaded
094-79922	Bearing, Pivot Spring Seat
130-98561	Piston Diff Pressure Transducer
110-98562	Spring Compression, Helical
111-98564	Seat, Spring Diff Pressure Transducer
111-98565	Seat, Spring Diff Pressure Transducer
043-98569	End Cap Diff Pressure Transducer
091-98570	Retainer, Threaded Diff Pressure Transducer

ITEM V.

BODY FLAP

SPACE SHUTTLE DATA
ORBITER HYDRAULIC SUBSYSTEM

Rev. 7/21/78 Sht. 1 of 2

SPECIFICATION NUMBER		COMPONENT	SUPPLIER	PART NUMBER		ASSEMBLY NUMBER		PARTS LIST		LIST OF MATERIAL		REMARKS
MC621-0066-0003	B	Power Drive Unit Layout	Sundstrand			EP6038-1	N		√		N	
"	/	Hydraulic Motor	Abex Sundstrand			63050 8900767	C		/		/	
"	/	Solenoid Contr Valve	Fluid Regulators			Not yet Completed	N		NJ		N	
MC286-0076-0001	/	Oleophobic Filter	Arkwin			0711325-106	-		/		/	Also ordered for rudder/speedbrake. See IV-9
"	/	Shaft Seal Drain Manifold	R.I.			V070-585408	A		/		/	
"	/	Shaft Seal Drain Hose	R.I.			V070-585406 ⊕	A		/		/	⊕ Also on R/SB
"	/	Hyd Subsystem Body Flap				V070-585090	A		/		/	
	/	Layout, Valve Pack	Sundstrand			EP6038-1001	-		/		/	
MC621-0056-0003	/	Valve Pack	Sundstrand		U	5001725	E		H		H	
"	/	Housing Assy. Valve	"			5002274	V		-		/	
"	/	Housing Sets, Valve	"			5001726	AY		-		/	
"	/	Housing Valve	"			5002276	N		/		-	
"	/	Outline Power Drive Unit	"			5001403	U		/		/	
		NOTES: * = Data is a part of the drawing.										
		A, B, C, etc. = Change letter of document in our files.										
		(- = No change)										
		N = This document is needed.										
MC621-0056-0003	/	Power Drive Assy	Sundstrand			5001413	F		*		*	
"	/	Insert	Sundstrand	5002200	-				*		*	
"	/	Insert	Sundstrand	5002201	-				*		*	
"	/	Gasket	Sundstrand	5003278	B				*		*	
"	/	Hydraulic Motor	Sundstrand			5900767	C		*		*	*SCD for Abex P/N 68050
"	/	Plug	Sundstrand	5900948	E				*		*	
"	/	Pin	Sundstrand	5900949	C				*		*	
"	/	Adapter, Fluid Conn.	Sundstrand	5902288	-				*		*	
"	/	Adapter Fluid Conn.	Sundstrand	57386-3	K				*		*	

ITEM V

BODY FL

SPACE SHUTTLE DATA

Rev. 7/21/78 V

Sht. 2 of 2

SPECIFICATION NUMBER		COMPONENT	SUPPLIER	PART NUMBER		ASSEMBLY NUMBER		PARTS LIST	LIST OF MATERIAL	REMARKS
MC621-0056 -0003	/	Plug, Lee Jet	Sunstrand	5900815	D			*	*	
"	/	Plug, Orifice	"	5900828	—			*	*	
"	/	Outline, Power Drive Unit	"			5001403	U	*	*	
"	/	Valve Pack Assy.	"			5001725	GE	*	*	
"	/	Valve Housings Matched Set	"			5001726	AY	*	*	
"	/	Stem & Sleeve Matched Set	"			5001728	M	*	*	
"	/	Sleeve, Valve Control	"	5001729	A			*	*	
"	/	Stem, Valve Control	"	5001730	D			*	*	
"	/	Spring, Helical Compr.	"	5001732	A			*	*	
"	/	Seat, Ball	"	5001746	-			*	*	
"	/	Spring, Helical Compr.	"	5001747	A			*	*	
"	/	Stem & Sleeve Matched Set	"			5001748	B	*	*	
"	/	Sleeve, Valve Recirculation	"	5001749	B			*	*	
"	/	Stem, Valve Recirculation.	"	5001750	C			*	*	
"	/	Spring Helical Compr.	"	5001752	A			*	*	
"	/	Plug	"	5001753	-			*	*	
"	/	Plug	"	5001829	B			*	*	
"	/	Valve, Solenoid	"			5902073	A	*	*	
"	/	Linkage	"			5003413	G	*	*	
"	/	Linkage	"			5003414	N	*	*	

YI

ITEM VI
EXTERNAL TANK RETRACT

SPACE SHUTTLE DATA
ORBITER HYDRAULIC SUBSYSTEM

Rev. 7/21/78

SPECIFICATION NUMBER		COMPONENT	SUPPLIER	PART NUMBER		ASSEMBLY NUMBER		PARTS LIST		LIST OF MATERIAL		REMARKS
MC287-0050-0002	A	E.T. Retract Actuator	Bertea			261600	B		—		—	
MC277-0002-1013	/	Hose Assembly	Titeflex			106080-1013	A		*		*	
	/	Hydr Sys IMST E.T. Actuators	R.I.	585055	-		/		*		/	
MC287-0050	/	Manifold Asst	Bertea			261650	C		/		*	
MC-287-0050-	/	Manifold Housing	Bertea	261651	-		/		/		*	
"	/	End Assy	Bertea			261643	-		/		*	
"	/	Piston Assy	Bertea			261668	-		/		*	
"	/	Piston Assy	Bertea			261641	-		/		*	

NOTES: * = Data is a part of the drawing.

A, B, C, etc. = Change letter of document in our files.

(- = No change)

N = This document is needed.

ITEM VII

MAIN LANDING GEAR

SPACE SHUTTLE DATA
ORBITER HYDRAULIC SUBSYSTEM

Rev. 7/21/78

VII

Sht. 1 of 2

SPECIFICATION NUMBER		COMPONENT	SUPPLIER	PART NUMBER	ASSEMBLY NUMBER		PARTS LIST		LIST OF MATERIAL		REMARKS
MC287-0034-0007	E	MLG Actuator (Strut)	Bertea		267800-1001	B		–		–	
MC284-0469-0006	B	L.G. Isolation Valve	Wright		15856	C		*		*	2 sheets
MC621-0029-0001	C	L.G. Control Valve	Sterer		55800	H		*		*	
MC621-0046-0003	D	L.G. Dump Solenoid Valve	Sterer		54070-2	J		*		*	
MC287-0034-0007	/	Manifold Assy L.G. Actuator	Bertea		267850	D		–		–	
ME271-0079-1001	/	Hose Assembly	Titeflex		106056-1001	D		*		*	Already listed in power Sys & N.G. steering
MC284-0469-0004	B	L.G. Shutoff Valve	Wright		15845	J		–		–	
MC621-0024-0100	/	Quick Disconnect	Symmetrics		501100-0100	/		/		/	See Item I, page 2
MC287-0034-0007	/	MLG Retract Cylinder	Bertea		246340-1003	C		–		–	
MC287-0033-0002	E	Uplock Actuator	Bertea		269400-1001	–		*		*	Dupl
	/	Hyd Subsystem L.H. MLG Wheel Well	R.I.		V070-586125	–		/		/	
	/	Hyd Subsystem R.H. MLG Wheel Well	R.I.		V070-586130	–		/		/	
	/	Hyd Subsystem MLG Strut	R.I.		V070-586220	–		/		/	
ME284-0434-1012	/	Check Valve	Crissair		4C3012	D		–		–	
	/	L/O MLG Plumbing	R.I.		VL70-586306	A					
MC284-0469-0005	/	Brake Isolation Valve	Wright		15844	F		–			
		NOTES: * = Data is a part of the drawing.									
		A, B, C, etc. = Change letter of document in our files.									
		(– = No change)									
		N = This document is needed									
MC287-0034-0007	/	Filter (SCD)	Bertea		267808	E		/		/	N/A 267800
*	/	Lap Assy Shuttle V	Bertea		267810	–		*		*	N/A *
*	/	Valve Assy, Check	Bertea		267830	A		*		*	N/A *
*	/	Valve Assy, Flow Cont Retr	Bertea		267860	–		*		*	N/A *
	/	Brkt - Flex Hose MLG QD	R.I.		V070-586223	–		*		*	Not requested N/A 586220
	/	L/O MLG Brake Lines MLG Strut	R.I.		V070-586304	–		/		/	

ITEM VII
MAIN LANDING GEAR

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SPACE SHUTTLE DATA
ORBITER HYDRAULIC SUBSYSTEM

SPECIFICATION NUMBER		COMPONENT	SUPPLIER	PART NUMBER		ASSEMBLY NUMBER		PARTS LIST		LIST OF MATERIAL		REMARKS
MC287-0034-0007	/	Piston	Bertea	246341-1	N				*		*	
•	/	Cylinder Assy	Bertea			246342-1	N		*		*	
•	/	Rod End Assy	Bertea			246343-1	N		*		*	
•	/	Gland Assy	Bertea			246344-1	N		*		*	
•	/	Ring	Bertea	246345	N				*		*	

ITEM VIII

WHEEL/BRAKES

SPACE SHUTTLE DATA

ORBITER HYDRAULIC SUBSYSTEM

Rev. 7/21/78

VIII

SPECIFICATION NUMBER		COMPONENT	SUPPLIER	PART NUMBER		ASSEMBLY NUMBER		PARTS LIST		LIST OF MATERIAL		REMARKS
MC 621-0055 0007	D	Brake/Skid Contr Module Assy	Hydroair			33-017-1 ●	N		*		-	81982
MC 621-0055 -0007	/	Brake/Skid Comtr & Antiskid Valve	"			33-529 ●	N		/		N	
"	/	Switching Valve	"			33-01727 ●	N		/		N	
	/											
"	/	Displacement Limiter	Hydroair			33-017502 ●	N		/		N	
"	/	Filter-Brake Outlet Module *	"			33-017501	N		/		N	
ME449-0177 -6106	/	Pressure XDCR	Statham			PA8203-2000-20702 @N Dwg 58969	-		/		/	See File I-1
MC 621-0055 -0009	/	Pressure Regulator	Hydroair	48-042	B	48-043	B		/		/	
	/	Mechanical Disconnect (QD) Valve	Symmetrics	Nipple → Coupler →		11362-5106-06P-N1 11362-5406-06M-N1	N		/		N	
ME 271-0079 -1001	/	Hose Assy	Titeflex			106056-1001	/		/		/	
MC621-0051 -0003	C	Wheel Assy, MLG	BFG			3-1359-1	N_T	(Chg Letter)	/		-	
-0004	/	Brake Assy, MLG	BFG			2-1357	U		/		*	
MC621-0050 -0001		Wheel Assy, NG	BFG			3-1361-1	/		/		-	
		*For inlet filter see 33-01727										
		@Proprietary										
		Schematic Diagram Brake Subsystem	R.I.	V070-520102	A		/		/		/	
		Control Valve Assy Brake Subsystem	R.I.	V070-586127	-		/		*		/	

NOTES: * = Data is a part of the drawing.

A,B,C, etc. = Change letter of document in our files

(-- = No change)

N = This document is needed.

ITEM IX
NOSE LANDING GEAR

SPACE SHUTTLE DATA
ORBITER HYDRAULIC SUBSYSTEM

Rev. 7/21/78

IX

SPECIFICATION NUMBER		COMPONENT	SUPPLIER	PART NUMBER		ASSEMBLY NUMBER		PARTS LIST		LIST OF MATERIAL		REMARKS
MC 287-0034 -0008	E	Strut Actuator	Bertea			267900-1001	B		—		—	See VII-1
"	/	Cylinder Assy	"			246440-100-1003	C		—		—	
"	/	Manifold Assy	"			267950-1003	E		/		*	
"	/	Transfer Tube	"			267903-1	-		/		*	
"	/	" "	"			267902-1	A		/		*	
MC 287-0035 -0002	D	Unlock Actuator	"			269500-1001	-		*		*	
MC287-0034	/	Lap Assembly Shuttle V.	"			267910	-		*		*	N/A 267900
"	/	Cap Assy-Shuttle V	"			267980	-		*		*	N/A "
	/	Hyd Syst Instl Nose Gear	R.I.	V070-582035	-				*			

NOTES: * = Data is a part of the drawing.

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ITEM X

NOSE WHEEL STEERING

SPACE SHUTTLE DATA

ORBITER HYDRAULIC SUBSYSTEM

Rev. 7/21/78

SPECIFICATION NUMBER		COMPONENT	SUPPLIER	PART NUMBER		ASSEMBLY NUMBER		PARTS LIST		LIST OF MATERIAL		REMARKS
MC 621-0058 -0002	Q	Command Servo & Steering Act.	Sterer			54410 *	J		N		N	
ME 271-0079 -1001	/	Hose Assy	Titeflex			106056-1001	/		/		/	Already listed for main landing gear
	/	Schematic N.W. Steering	R.I.	VS70-510202	A		/		/		/	
		*Proprietary										

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APPENDIX D

CHECKLISTS

Check Lists
for
Space Shuttle Hydraulics

Part I
Definition

1. Purpose - To aid in the review of the space shuttle hydraulic system and identify problems of design, manufacturing control or inadequate testing that could result in a Category 1 failure.

2. Circumstances leading to a failure:

   Failures are presumed to result from:

   a. Poor design practices or failure to anticipate and properly account for real operating conditions.
   b. Inadequate manufacturing controls or fabrication errors.
   c. Qualification and acceptance tests which do not identify design weaknesses or improperly made parts.

   Failures resulting from these causes may develop in a short or long time. To be considered Category 1 they must result in a catastrophic situation by themselves or in combination with a prior undetected failure. A generic failure will be considered a single point failure where a design deficiency is typical in all three redundant systems.

Part II ❶
Failure Modes of Components

1. Major loss of system fluid
   - o Rupture of fluid containers
     - Pressure surges
     - Intergranular corrosion
     - Plugged drains
   - o Failure of a seal
   - o Failure of tubing or fitting connections

2. Component ceases to operate
   - o Jammed by foreign material
   - o Loss of seal alters forces
   - o Spring failure alters forces
   - o Thermal shock causes binding
   - o Failure of attachments (bolts/nuts)
   - o Plugged filters or orifices
   - o Structural failure of components
   - o Short L/D of pistons causes lockup
   - o Electrical interface failure

3. Component operates erratically*
   - o High internal friction resulting from dirt or binding
   - o Failure of a seal
   - o Deformation of a sealing or metering metal surface
   - o Plugged passages
   - o Excessive wear of metal parts
   - o Galling

❶ Actuators, fluid containers, valves, lines and pumps/motors
* Slow or out-of-tolerance response.

Reminder Check List

1. Packings
   - Backups
   - Entrance Chamfer & finish
   - Leakage - major
   - Leakage - minor
   - Permanent set
   - Redundancy

2. Environment
   - High Temperature
   - Thermal conditioning
   - Low Temperature
   - Thermal shock
   - Vibration
   - Humidity
   - Salt Water/Atmosphere
   - Breathing due to altitude
   - Effect of condensation
   - Space vacuum effects

3. Freedom of motion
   - Tight fit
   - Loose fit
   - Load deflection
   - Thermal expansion
   - Friction
   - Contamination
   - Galling

4. Fluid
   - Pressure surges
   - Viscosity
   - Contamination
   - Compatibility

5. Qualification Testing
   - Operating conditions
   - Total cycles and time
   - Environments
   - Proper instrumentation
     - Transducers & recorders

6. Acceptance Testing
   - Operating conditions
   - Total cycles and time
   - Environments

7. Materials
   - Suitability
   - Hardness
   - Strength
   - Galvanic corrosion

8. Conventional Design

9. Fluid Lines
   - Supports
   - Fittings
   - Materials
   - Serviceability
   - Compliance with struct. defl.

10. Redundancy
    - Backup systems
    - Separation of systems
    - Different source of power, e.g. electric, ordnance, pneumatic gravity

11. Service History

    Airlines

    Aircraft/spacecraft manufacturers

    Military

    NASA/space systems

    Manufacturers - component testing laboratories

Design Check List

1. Consider loads, energy, operating time, sensitivity. Establish satisfactory operation under Extreme Conditions: temperature, humidity, corrosion, vibration, voltage, wind, dirt, ice.

2. Provide optimum Safety under misuse or failure.

3. Minimize Stress Concentrations.

4. Consider the effects of Deflections and Friction.

5. Components which receive Limit Loads Each Time they are used, i.e. arresting gear, catapult gear, and parts of the landing gear, must be investigated critically for Stress Concentration and Stress Levels and must demonstrate reasonable service life by Fatigue Testing.

6. Prevent Incorrect Connections through design configuration. Ensure that designs are "Murphy Proof" by controlling configuration to prevent inadvertent assembly that causes damage or malfunction.

7. Any essential service (landing gear, arresting hook, flaps, etc.) shall have an Alternate Method of Actuation.

8. Provide adequate sealing to prevent the entrance of Foreign Materials.

9. Stops - Parts designed as stops or absorbers of store energy must not deflect sufficiently to cause malfunction.

10. Distortion of parts due to pressure, thread loads, manufacturing holding loads, gasket loads, interference fits, etc., must be considered.

11. Crossed Lines and Controls - Every effort shall be made to assure that it will be physically impossible to incorrectly install cables, levers, cranks, hydraulic lines, or any other parts that can cause malfunction.

12. Air Bleeding - Provision must be made for bleeding brakes and other systems where displaced volume is less than line volume and where the presence of air could cause malfunction.

13. Gasket Static Seal Installation should be designed in accordance with accepted practices.

14. Face Seal O-Rings should be backed with backup ring or equivalent.

15. Face Seal Deflection - Cover plate deflections under maximum operating pressure in combination with out-of-flatness of the mating faces must not expose the face seal to extrusion gapping in excess of 0.004 inch, for an O-ring with backup. For unbacked static seat O-rings, extrusion gapping must not exceed 0.0005 inch.

16. O-Ring Packing Installations should be designed in accordance with military standards. Where loss of O-ring will allow external leakage, provide barrier seal.

17. Corrosion Protection at Packings - All parts which slide across packings should be smooth, chrome-plated, hard-anodized, or be of corrosion-resistant material. Packing grooves and static seal glands should be similarly protected or plated anodized.

18. Corrosion Resistance - Materials, surface coatings, and material combinations must provide suitable corrosion resistance, both inside and outside.

19. Aluminum Alloy Mating Parts should not be used in bearings or in frequently used threads. (Example: Reservoir filler plug.)

20. Case Hardening - Latches, cams, triggers, and similar parts subject to possible wear with high bearing pressure should be hardened to Rockwell 30-N 76 minimum or equivalent.

21. Avoid Pipe Threads.

22. Retainer or Snap Rings shall not be used where ring failure could allow blow-apart of the unit, or where end-play could allow failure of seals or other parts.

23. Standard Designs
    a. Torque Notations of Joints - Wrench torque for preload should be specified on the following joints:
        1. Face seal joints
        2. Any special joint requiring preload
    b. Orifices - Must be larger than maximum filtration. Unfiltered orifices must be larger than .090.
    c. Flexible Hose Specifications - Per MIL-H-5440.
    d. Line Clamps Spacing - Line-clamp maximum spacing is specified in MIL-H-5440. Mount fittings and valves close to supports.

24. Crossed Lines and Controls - Every effort shall be made to assure that it will be physically impossible to incorrectly install cables, levers, bellcranks, hydraulic lines or any other parts that can cause malfunction.

25. Test Notes - Each production unit of a hydraulic assembly must be tested. Test notes shall be specified on the assembly drawing or test requirements document.

26. Do not locate hydraulic fitting bosses on forging plane.

27. Select forging materials not susceptible to stress corrosion.

28. Expansion type plugs (Lee plugs) should have backup retention where fluid loss results in critical safety condition.

Part III

System Influence on Component Failure

1. How can systems be designed to tolerate component failures?

2. Does the system create operating conditions which cause component failures?

3. Minimize connections.

4. Pressure surges from rapid valve operation and actuating cylinders bottoming.

Service and Maintenance

1. Consolidate modules to provide fewest disconnections in vehicle.

2. Provide drip pans to collect fluid during servicing operations. (Seal skins, stringers and bulkheads to direct drippings and condensate to selected location.)

3. Provide protective shields, boots and lubricators to prevent contamination of sliding and rotating equipment.

ADDENDUM

HYDRAULIC SYSTEM ASSESSMENT
WATER SPRAY BOILER

WATER SPRAY BOILER ASSESSMENT

1. SCOPE

A group of 37 drawings and specifications was supplied to Douglas Aircraft Company in late June 1978. This was too late for them to be included in the final report in Washington, D.C. or in the main body of this report.

The assessment of the water spray boiler is confined to the components directly associated with the hydraulic power system and to its effect, as a whole, on the power system. The main areas of concern are the spray boiler heat exchanger and the hydraulic bypass and relief valve.

2. FAILURE EFFECTS

Each hydraulic power system has its own water spray boiler, and there is no functional connection between them. For this reason, the single failure points that exist affect only one hydraulic power system and cannot cause a Criticality Category 1 condition. The three water spray boilers are installed near each other just aft of bulkhead 1307. A single catastrophic event such as an explosion could therefore damage more than one of them. This would result in a Criticality Category 1 condition.

3. HEAT EXCHANGER, WATER SPRAY BOILER

The entire heat exchanger construction is of good quality materials assembled by conventional methods. The design appears to be good and suitable for the purpose. Development, qualification, and acceptance testing requirements seem adequate. The probability of major or minor hydraulic leakage seems low because of the type of construction used. The 1/8-inch-diameter hydraulic tubes are necked down to about three-fourths of their normal diameter (approximately 0.075 inch) at about 2-inch intervals. Because of the large number of tubes, the blockage of a significant number of them by contaminants does not seem likely to occur. These small tubes appear to be adequately supported, and vibration should not cause problems. The heat exchanger is unlikely to cause hydraulic system problems.

4. HYDRAULIC BYPASS AND RELIEF VALVE

The bypass and relief valve is made of materials which are suitable for the purpose. The seal SV766536-1 is made of filled Teflon and is not a conventional hydraulic design. It may nevertheless be satisfactory for this valve. The Hamilton Standard Specification SVHS 7312 specifies allowable leakages in terms of scc/sec of helium and "X" pph. These would be better if specified in terms of cubic centimeters or drops in a specific time period, which is conventional hydraulic practice. The design appears to be good for this application.